RESNA 2000

Technology for the New Millennium!

PROCEEDINGS

RESNA

TECHNOLOGY FOR THE NEW MILLENNIUM

ANNUAL CONFERENCE

OMNI ROSEN HOTEL

ORLANDO, FLORIDA

JUNE 28 — JULY 2, 2000

PROCEEDINGS
of the
RESNA 2000
Annual Conference

Technology for the New Millennium

June 28-July 2, 2000

Omni Rosen Hotel
Orlando, Florida

Jack Winters, PhD
Editor

Jody Whitmyer, ATP/S CRTS
Terry Ward, PhD ATP
Conference Co-Chairs

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Foreword

On behalf of the local organizing committee we welcome you to Orlando for the RESNA 2000 Annual Conference. Orlando is an extraordinary example of the power of one person's dream, and what can happen when you follow your dreams! In just thirty short years, the city of dreams has risen from a swamp to one of the world's most popular tourist and recreational locations. Just as one man had the vision for what could be accomplished when you combine imagination and technology, we know you'll find this year's conference packed full of vision.

Technology can often be the link that helps make dreams come true for persons with disabilities. At this year's conference, you'll have the opportunity to connect with a vast array of technologies that play a key role in transforming lives every day. The exhibit hall will be teeming with products ranging from seating and mobility aids; sensory aids; ergonomics and accessibility aids; to computer access devices and recreational aids. You'll have the chance to try many devices and connect with manufacturers of these products, sharing your insight and knowledge.

The RESNA Annual Conference is the event where clinicians, suppliers, educators, researchers, and consumers gather to share information and expertise, to teach and learn from one another.

We hope you will find both the conference and the city of Orlando to be exciting and inspiring! Enjoy the conference, and return home to realize your dreams!

Jody Whitmyer, ATP/S CRTS
Terry Ward, PhD ATP
RESNA 2000 Conference Co-Chairs

Alexandra Enders, OTR/L ATP
RESNA President

Preface

Welcome to RESNA 2000. This year's theme, Technology for the New Millennium, provides a focus for over 200 presentations on all facets of assistive technology through concurrent sessions, scientific platform sessions, interactive poster presentations, computer demonstrations, and the Research Symposium.

This Proceedings of the RESNA Conference attempts to capture some of the information that will be exchanged during the activities and events of the Conference. The scientific papers included in this document contain everything from recent scientific research to practical designs to case studies. Scientific content is grouped into 8 categories:

- Technology for Special Populations
- Augmentative and Alternative Communications
- Computer Access and Use
- Environmental Accommodations
- Functional Control and Assistance
- Service Delivery & Public Policy
- Research and Functional Outcomes
- Seating and Mobility

Papers from the Sixth Annual Research Symposium on Ergonomics are part of this Proceedings, as are the winning papers for the Student Scientific Paper and Student Design competitions.

RESNA 2000 resulted from the efforts of many people. Tony Langton, in particular, has led the planning and organizing at both the local and national levels. Thanks go to Brenda Sposato, coordinator for the concurrent sessions which parallel the scientific sessions, and to the eight topic coordinators for the review process of the scientific papers: Cheryl Trepagnier, Frank DeRuyter, Glen Ashlock, Molly Story, Ron Triolo, Nancy Meidenbauer, Jeff Jutai, and Mark Schmeler. Thanks also goes to the numerous reviewers of the individual scientific papers for their efforts in determining the final program. Tom Armstrong and Randy Rabourn are to be commended for their leadership in shaping the Ergonomics Research Symposium. As always, the efforts of Susan Leone and Terry Reamer are greatly appreciated.

Enjoy the Conference.

Jack Winters, PhD
Chair, Scientific Program

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A NEW METHOD FOR INTERFACE PRESSURE MEASUREMENT IN COMPRESSION SHRINKERS FOR PATIENTS WITH TRANS-TIBIAL AMPUTATION

Duncan Bain, Martin Ferguson-Pell, Patrick Davies, Laura Burgess
Centre for Disability Research and Innovation
University College London

ABSTRACT
The authors have developed a technique for inferring the interface pressure applied by a compression shrinker, from measurements of the local weave spacing and local radius of curvature, together with knowledge of the elastic properties of the shrinker fabric. This technique does not require the interposition of a sensor at the interface, and so circumvents the associated artefacts. The technique is found to be sensitive, accurate, and stable over a wide range of topologies and clinically relevant pressures, and compares favourably with state-of the art interface pressure sensors.

BACKGROUND

Two major goals in the postoperative management of residual limbs of patients with lower limb amputation are the prevention of oedema formation and facilitation of stump shrinkage. Elastic bandaging and compression shrinkers are commonly used to control limb oedema during the pre-prosthetic period.

A study by Manella (1) proposed that elastic shrinker socks should be used as a method of choice and found they were more effective than bandaging in reducing residual limb volume based on the results of 4 weeks monitoring. A survey of 35 artificial limb units (with a 97% response rate) indicated that 100% of them were using stump shrinkers and 85% of the units gave them to every patient. (2)

However, concerns have been raised over the potential causation of skin breakdown and distal oedema (3). Little research has been undertaken to investigate the level of pressure required to facilitate stump shrinkage while maintaining blood circulation. Veraart et al (4) evaluated the pressure using small-cell pneumatic interface pressure sensors (Oxford Pressure Monitor MKII, UK) when wearing elastic stocking for the treatment of venous disease.

Interface pressure measurement is beset with problems (5). These include the changed conditions caused by the presence of the sensor in the system (6), artifacts due to curvature of the sensor (7), integration errors over the active area of the sensor (8), and uncertainty of the location of the sensor at the interface (9). Piezoresistive type sensors are also subject to temperature stability errors, hysteresis, and drift.

AIMS

The authors have developed a technique for inferring the interface pressure applied by a compression shrinker from measurements of the local weave spacing and local radius of curvature, together with knowledge of the elastic properties of the shrinker fabric. This technique does not require the interposition of a sensor at the interface, and so circumvents the errors listed above. The aim of this study is to validate the technique by calibration against known applied interface pressure, and to compare the performance with that of a commercially available sensor (Flexiforce, TEKSCAN, USA).

PRINCIPLE OF OPERATION

Pressure applied by a taut membrane is a function of membrane tension, and radius of curvature of the surface over which the membrane is stretched. For a material with anisotropic elastic properties, tension and curvature must be considered in 2 axes. A calibration curve is generated for a given elastic textile in a simple test-rig, to relate tension to weave spacing. Tension can be determined locally by measurement of weave spacing in each axis. Curvature parameters as defined in figure 1 can be measured locally in each axis by external placement of the 'cylindrometer' developed by the authors, pictured in figure 2. The authors propose a formula (A) to derive interface pressure:

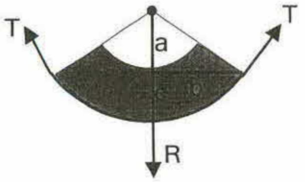

Figure 1

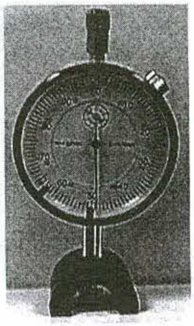

Figure 2

$$P_{int} = \frac{4 \times T_x \times c_x}{b^2 + c_x^2} + \frac{4 \times T_y \times c_y}{b^2 + c_y^2} \quad (A)$$

METHOD

A large inflatable air-tight bag was connected to an air-tube and placed inside a compression shrinker (Juzo, UK). The size of the bag selected was substantially larger than the shrinker, so that the membrane of the bag was not in tension when inflating the shrinker, and the air pressure was reacted against by the shrinker alone.

A Flexiforce interface pressure sensor was placed at the interface between the bag and the shrinker. The bag was pressurised to 20mmHg in increments of 2mmHg, as measured using a Digitron 2022P digital pressure gauge. At each increment, the interface pressure output from the Flexiforce (pre-calibrated in a flat calibration chamber) was recorded. This was repeated 6 times, with the sensor repositioned within the shrinker each cycle. Similarly at each increment measurements were made of bi-axial weave spacing using Vernier calipers spanning 10 warps/wefts, curvature was measured biaxially at the same location using the cylindrometer, and interface pressure calculated using formula (A). These measurements were made in a variety of locations on the shrinker with different degrees of convexity.

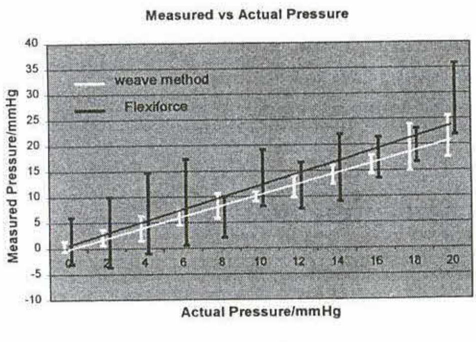

Figure 3

RESULTS

Figure 3 shows pressure calculated from the weave spacing and curvature (white), and Flexiforce output (black) plotted against actual air pressure applied within the shrinker. Error bars indicate standard deviations for the 6 measurements at each increment, and the lines indicate regression curves for the means. It can be seen that the errors associated with the weave spacing technique are generally smaller than those of the Flexiforce. The formula (A) appears to generalise well for different degrees of curvature, and apply to both spherical and cylindrical shapes. Good temporal stability was also noted in the weave spacing technique, whereas the Flexiforce output creeps substantially with log time (see figure 4).

CONCLUSIONS

Biaxial measurement of weave spacing and curvature, together with knowledge of the elastic behaviour of the material, and a formula (A), provides a robust technique for the inference of interface pressure applied by compression shrinkers. The temporal stability of the technique allows measurements to be made over a prolonged period. A critical advantage of the weave spacing technique is the absence of a sensor at the interface, which can cause perturbation of the quantities being measured, and which commits the user early to a specific site of measurement. A sensor at the interface may also obstruct other modalities of measurement that may be required (e.g. photospectrometry) at the same site.

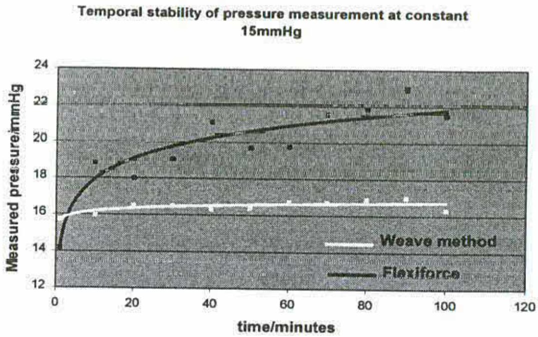

Figure 4

Duncan Bain, Centre for Disability Research and Innovation, Institute of Orthopaedics, UCL, Brockley Hill, Stanmore, Middlesex, UK HA7 4LP frankiehowerd@netscape.net

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A NOVEL PROBE FOR THE MEASUREMENT OF SKIN BLOOD CONTENT AND OXYGENATION IN THE RESIDUAL LIMB WHILE WEARING A COMPRESSION SHRINKER

Martin Ferguson-Pell, Duncan Bain, Patrick Davies, Laura Burgess
Centre for Disability Research and Innovation
University College London

ABSTRACT
The authors have developed a novel spectroscopic probe that can be used to measure skin blood content and oxygenation non-invasively through the weave of a compression stocking. The concept was proved by measuring the changes in these quantities in primary patients with transtibial amputation while wearing a shrinker over a period of 50 minutes. The probe is successful in delivering light that has interacted with the microvasculature. Longitudinal traces showed variations in skin blood content and oxygenation with application and removal of the shrinker. Further work, combining TRS with local interface pressure measurements, is required to characterise the dynamic relationships between IHB, IOX, and applied pressure.

BACKGROUND
Following transtibial amputation, reduction of oedema is necessary prior to casting for a prosthesis in order to achieve a good fit for the prosthetic socket.(1) Elastic bandaging or compression shrinkers are commonly used for this purpose, and can shorten the time to ambulatory discharge(2).

The majority of transtibial amputations are performed on elderly patients, and are directly or indirectly caused by peripheral vascular disease or diabetes (3). Both these conditions predispose patients to ischaemic skin breakdown (4), and over 45% of amputees in this group require a subsequent, more proximal amputation as a result.(5) Concerns have been raised over the use of compression shrinkers and the possible effects in terms of ischaemia, delayed wound healing, and constriction. (6) To date there has been no quantitative research undertaken into the effects of wearing a compression shrinker on the microcirculation in the skin of the residual limb. Understanding this relationship would provide a basis for optimal use of the shrinker in rehabilitation.

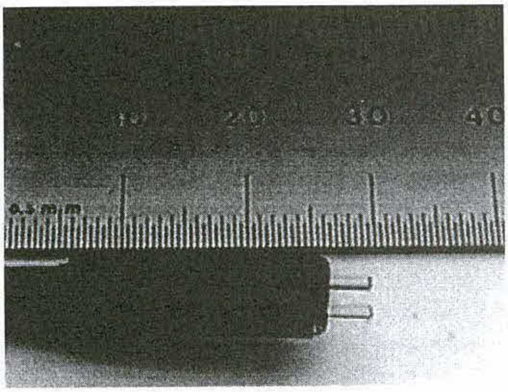

Figure 1: the probe

AIMS
The authors have developed a novel spectroscopic probe that can be used to measure skin blood content and oxygenation non-invasively through the weave of a compression stocking. The purpose of this study is to prove the concept by measuring changes in blood content and oxygenation in patients with transtibial amputation while wearing a shrinker over a period of 50 minutes.

OPERATING PRINCIPLE

Tissue reflectance spectroscopy (TRS) can be used to measure blood content and oxygenation in skin. A fibre-optic bundle is used to deliver white light and collect back-scattered light from the skin. The back-scattered light can be analysed for spectral components that have been modulated by the blood.(7) Using appropriate algorithms it is possible to determine indices of blood content (IHB) and oxygenation (IOX) of the superficial vasculature, independent of melanin pigment.(8)

The authors have developed a probe, shown in figure 1, in which single polymer fibres respectively send and collect light. Each fibre has a diameter of 1mm, and protrudes 3mm from a common shroud, which attenuates ambient light9. The end of each fibre is rounded so that it may be pushed through the weave of a compression shrinker. The sending and collecting fibres are space apart on 4mm centres. This design ensures that light passing from the sending to the collecting fibre passes diffusely through 3mm of intermediate tissue, which is not subject to direct loading from the fibre tips. The signal is consequently coded according to the blood content in the skin acted upon by the shrinker, not by the probe.

METHOD

Subjects included in the study were consenting primary (8-10 weeks post-operative) patients following transtibial amputation. Each subject was seated in a controlled environment (21°C +/- 2°C, 60%RH+/- 10%RH) with the residual limb supported in a horizontal position. 5 sites of interest were marked as circles using a surgical marker according to figure 2. After a 10-minute acclimatisation period, TRS measurements were made at each site using the probe. The shrinker was then applied to the limb, and the measurements repeated immediately using a pair of surgical tweezers to secure the shrinker fabric while manoeuvring the probe (see figure 3). 5 Further intervals. The shrinker was removed, and final measurements were taken immediately.

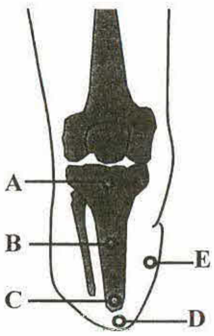

Figure 2: sites of measurement

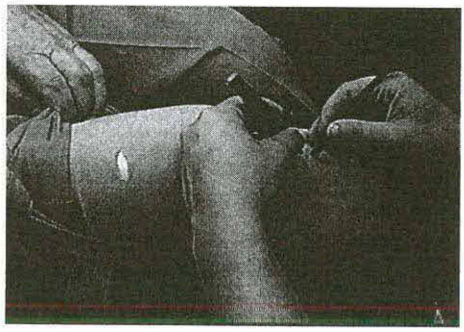

Figure 3: scanning technique

RESULTS

Figure 4 shows IHB and IOX traces for a single subject at the tibial tuberosity (site A). It can be seen that both quantities are depressed immediately after application of the shrinker. Thereafter, IHB recovers quickly, transiently exceeding the baseline level 20-30 minutes after application. IOX recovers more slowly, remaining significantly depressed until after removal of the shrinker at 50 minutes, whereupon both IHB and IOX return quickly to their approximate baseline levels. No overshoot is observed in either quantity, and no reactive hyperaemia was observed clinically upon removal.

As expected, some interaction is evident between IOX and IHB, although sampling intervals in this instance are too large to determine the leads and lags required to characterise this interaction. It was also clear from the full dataset (not shown), that sites differed in their sensitivity to the application of the shrinker. This may reflect the non-homogeneity of pressure applied by the shrinker to the residual limb.

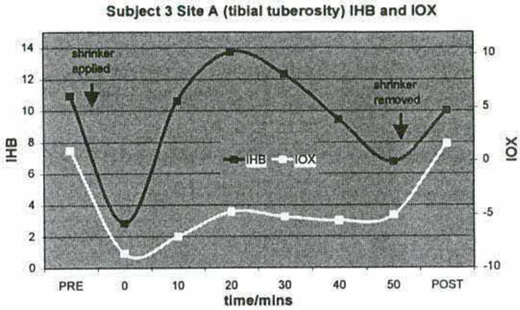

Figure 4: sample traces

CONCLUSIONS

The probe is successful in coding white light by interaction with blood in the skin. Instantaneous TRS traces showed characteristic blood signal both with and without a compression shrinker. Consistent with expectations, longitudinal traces showed variations in skin blood content and oxygenation with application and removal of the shrinker. Further work, combining TRS with local interface pressure measurements, is required to characterise the dynamic relationships between IHB, IOX, and applied pressure.

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OUTCOME MEASURE CONSIDERATIONS AND PRELIMINARY RESULTS FROM THE DESIGN AND TESTING OF THE CHIN DRY™ TECHNOLOGY

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Janet Allaire, M.A., Dept. of Pediatrics, University of Virginia Health System, Kluge Children's Rehabilitation Center, Charlottesville, VA

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ABSTRACT. The National Institutes of Health, National Institute of Child Health and Human Development funded the research, development and testing of the Chin Dry System™ (CDS™), to address the problem of saliva overflow (i.e., sialorrhea or drooling). The CDS™ technology keeps the user dry from unwanted saliva, serves as a research tool for professionals investigating the problem of saliva overflow, and includes training functions to ameliorate the condition (1). The research team considered a wide range of potential outcome measures to capture the efficacy of the technology and its social and psychological impact on research subjects. Research results, based on newly defined **NCMRR** measures, reliably demonstrated efficacy and positive effects.

BACKGROUND. This research is comprised of both a Feasibility Phase (Phase I) and a Research and Development Phase (Phase II). Involvement of consumers (research subjects) in product design and testing is critical to the success of both phases. The research team acknowledges the use of appropriate "Outcome Measures" for improving consumer satisfaction, efficacious design, enhanced function, and cost-effectiveness. With this in mind, researchers incorporated the **Functional Limitation Domain** and **Disability Domain** from the *Model for Classification Domains of Research* developed by the National Center on Medical Rehabilitation Research (NCMRR) (2).

Based on NCMRR recommendations, engineering and research design decisions considered the life-experiences of people with saliva overflow, included consumer feedback during every stage of product design and testing, and insured standard use of scientific method in both engineering and clinical applications. The research design integrated testing of the system's evolving prototypes with clinical and behavioral testing of subjects to address their social, psychological and personal concerns.

RESEARCH QUESTIONS

1. What is the reliability of the CDS™ for saliva removal and its other functions?
2. Does the research subject stay dryer from spilled saliva after using the CDS™?
3. Does the research subject experience self-concept, social, behavioral and psychological changes as a result of using the CDS™?
4. Does the caregiver experience attitudinal changes as a result of the CDS™?

METHOD. Phase I (Feasibility) allowed researchers to test and refine both the CDS™ prototype technology design and the various assessment methods and instruments. Involvement of research subjects during Phase I enhanced the efficacy of research conducted during Phase II. Thus far, 27 research subjects participated in both phases of the study. The sample was relatively balanced in terms of gender, ethnicity, and cognitive ability (both with and without mental retardation). All but two subjects have cerebral palsy. Ages range from 9-65. 19 of the 27 subjects assisted in the design and alpha testing of the CDS, and 8 youths participated in the clinical testing phase of the study.

Following the **NCMRR Functional Limitation Domain** model, researchers assessed individual subjects for the condition of saliva overflow and evaluated the CDS's effectiveness in keeping subjects cleaner and dryer. To permit evaluation of whether the CDS contributed substantially towards improved function and quality of life, the research addressed questions in three areas.

Technology Research. The CDS vacuums and stores unwanted saliva for disposal and logs system-operations data for subsequent analysis. The three saliva collectors are worn and used externally. The system is equipped with LEDs that visually indicate various operating CDS functions. Researchers performed continual visual checks of the CDS's LEDs to confirm that designated and expected functions occurred.

Functional Assessment of Research Subject. Parents and researchers evaluated research subjects using the **Saliva Assessment Instrument** (**SAI**) developed by Allaire and Adams (3). The **SAI** pinpoints four levels of severity of drooling: mild, moderate, severe and profuse. Four graphics visually depict how saliva overflow is manifest. The **SAI** also captures data on predictable patterns associated with increases and decreases in saliva overflow including saliva characteristics, dentition, swallowing capabilities, posture and seating. Brown enhanced this concept with sketches of consistent drooling patterns, body positions and functions impacting a person's tendency to drool.

Saliva Wetness Assessment. Researchers devoted considerable effort to developing an objective measure to gauge wetness due to saliva overflow. Prior research attempts to measure saliva overflow behaviors have typically been difficult and unreliable. Consequently, the research team decided to dress research subjects in either gray T-shirts or blue medical gowns that clearly indicated degrees of wetness due to saliva overflow on the shirtfront. Researchers photographed subjects approximately once every 15 minutes. Researchers ranked these photographs from least wet (dry) to saturated in a series of 5 photographs and scored them on a scale of 0-4. During random presentation of photographs, professionals familiar with saliva overflow validated this ranking scale at 90% agreement. Using these photos as the standard and at 5-minute intervals, researchers scored how wet the gown was. When the gown became saturated, it was replaced with a dry gown and scoring began anew. The CDS served as intervention in this ABAB single-subject research design.

The **NCMRR Disability Domain** measures the impact of saliva overflow on the lives of research subjects and evaluates whether potential consumers could realistically obtain the CDS technology. It accomplishes these objectives through use of assessment instruments in the following areas.

Social Assessment of Research Subjects. Due to the cognitive limitations of five participants, only three clinical research subjects answered a modified version of the **Quality of Social Functioning Scale** (**QOSF**) by Hayes et al. (4). The **QOSF** measures social functioning for adolescents with physical disabilities and "assesses the difference between adolescents' actual and desired participation in social activities". Hayes research shows that participation is oftentimes negatively impacted due to physical disability. Brown et al. modified appropriate questions to measure the impact of saliva overflow on research subjects' social experiences.

Cost Effectiveness from Query of Consumers, Caretakers, and Professionals. Brown and Allaire developed a questionnaire to gather demographic data describing the saliva overflow population and detailing those circumstances conducive to use of this assistive technology including purchase value. These questionnaires were distributed in person, at conference presentations and through the IHS, Inc.'s Saliva Overflow web-site (ihs.airweb.net) to consumers, caretakers and professionals.

RESULTS. Research data indicated that the CDS worked and kept the research subjects clean and dry and nine school staff had 100% agreement to this. Staff had 100% agreement that the CDS was designed correctly. The Saliva Assessment Instrument reliably diagnosed the condition of saliva overflow and provided critical clinical information about the subjects. The Saliva Wetness Assessment allowed researchers to reliably and objectively evaluate the CDS's effectiveness in keeping subjects dry. The modified Quality of Social Functioning Scale, administered to three subjects and one online consumer, generally indicated that the saliva overflow condition was an unwanted condition that interfered with several aspects of life but resulted in fewer friends in only one case. All would use an acceptable external device. The Query of Consumers, Caretakers and Professionals, answered by 11 respondents, generally indicated that the a saliva collector was worth $500, that 90% of the professionals wanted the training and research component of the CDS, 42% would try an external saliva collector, and 64% would try an internal saliva collector.

DISCUSSION. Total involvement of consumers as research subjects was essential in the CDS research. 80% of the caregivers and/or research subjects in the clinical trials could and would prefer to use a saliva collector that was inside the mouth if it was compatible with the subject. Clinical research subjects who had the cognitive ability to be queried (3 out of 4) did not want to use the CDS in a public forum. However, they quickly and consistently adapted to, and depended on, its ability to passively vacuum unwanted saliva in a non-public environment..

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DESIGN OF A MULTI-CHANNEL DATA LOGGER FOR RECORDING HYBRID III TEST DUMMY FORCES DURING LOW-IMPACT INCIDENTS

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ABSTRACT

This study focused on the design of a Hybrid III test dummy (HTD) forces during low-impact incidents, such as wheelchair driving tips and falls. The system consists of a HTD, force sensors that are mounted within the HTD, data logger and analysis software. The design of data logger, software and the position for sensors mounting are presented in this paper.

INTRODUCTION

There is an increasing trend in power wheelchair accidents annually (1)(2)(3)(4). There is little literature on the cause and prevention of these accidents. Currently no low speed, low impact hybrid test dummy (HTD) exists for crash studies. A reliable and accurate HTD is necessary for valid results and ultimately the reduction in accident frequency and severity. In order to provide the wheelchair user with crash protection, design criteria that can keep the wheelchair user safe during a crash should be established. In this study, we are focusing on the design and validation of the HTD.

A 50^{th} percentile Hybrid III test dummy forms the basis for the development of a low impact HTD. We mounted twenty-four force sensors to the HTD knee, chest, neck, and head. An important aspect of the HTD design is the ability to collect crash data without a tether that may influence the crash dynamics. We developed a multi-channel data logger system. The system consists of a batteries powered data logger and analysis software on a PC. We used micro-controller in the data logger design. The data collected during test dummy crashing is stored in flash memory and is transmitted to a PC through an RS-232 serial port. User friendly analysis PC software is programmed in Windows using Borland C++ Builder 4.0 language.

METHOD

The system multi-channel data logger for recording Hybrid III test dummy (HTD) during low-impact incidents consists of 24 force sensors, data logger and analyzing software. See Fig. 1

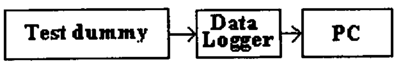

Figure.1 multi-channel data logger system

Twenty-four force sensors are mounted on different position of test dummy. Neck position six force sensors, both knee 4 sensors, lumbar spine 3 sensors, both instrumented leg 10 force sensors and chest 1 sensor.

The data logger consists of a micro-controller (Motorola-MC68HC11), 24 channel amplifiers, 4 analog switches, one flash memory chip, two LEDs, two keys and data transmitting interface circuit. See Fig.2.

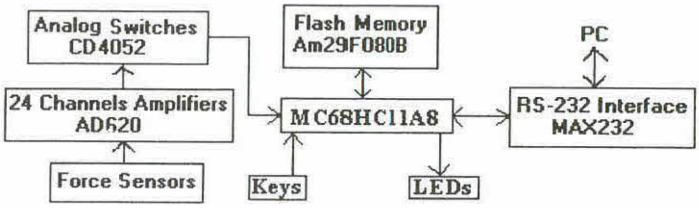

Figure.2 Schematic for data logger

The force sensors' signal is filtered and amplified. We use the IC AD620 as the pre-amplifier, it has good signal-to-noise, high input resistance and common mode rejection ratio (CMRR). Four analog switches CD4052 are used for selecting different channels signal to analog-to-digital converter, therefore 24 channels signal can be converted to digital signal.

There are two LEDs in the data logger to display the four operating modes. Mode 1: LED A on and LED B off (force sensors calibrating). Mode 2: LED B on, LED A off (flash memory chip erasing). Mode 3: Both LED A and LED B on (data collection from dummy). Mode 4, LED A on for 500ms, off for 500ms alternately (data transmitting from data logger to PC). Two keys are used to select the different operating modes.

We use a MAX232 chip for the Data transmission interface circuit. It contains four components: dual charge-pump DC-DC voltage converters, RS-232 drivers, RS-232 receivers, and receiver & transmitter enable control inputs. In the dual charge-pump voltage converter, there are two internal charge-pumps that convert +5V to ±10V (unloaded) for RS-232 driver operation.

SOFTWARE

The software consists of two parts. One is the software for data logger. Another is for a PC. We use Motorola assembly language for the embedded software. It contains four parts: (1) Sensor calibration (CPU samples data from each channel and sends to PC through transmitting interface circuit). (2) Collecting data (samples 24 channels of data and stores them into flash memory at a sampling rate of 600Hz for 30 seconds).(3) Flash memory erase (writes FFH into flash memory). (4) Data transmitting (send all the data stored in flash memory to PC for analysis). See Fig. 3.

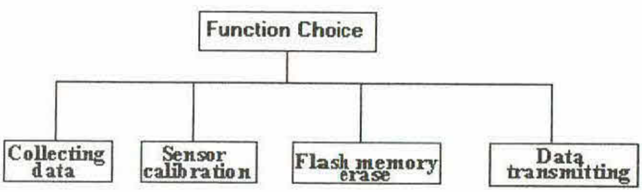

Figure.3 diagram of data logger software

We used Borland C++ Builder 4.0 language to design our PC software. The language is a fast, powerful ANSI C++ compiler and visual development environment for building high-performance Windows applications. Our software allows sensor calibration, loading data from data logger, and displaying data. During sensor calibration, the data for each channel can be displayed on the screen. Test data stored in the data logger can be received by a PC and displayed. We can display each channel separately, see Fig. 4.

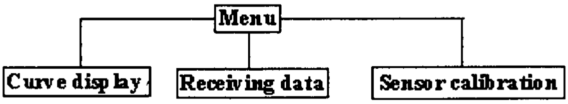

Figure.4 diagram for PC analyzing software

DISCUSSION

We introduced design of a multi-channel data logger system for recording Hybrid III test dummy forces and moments during low-impact incidents. The forces and moments must be recorded via a data logger in order to be able to study crashes in real-world environments without modifying the HTD dynamics. It is much better to use special memories (for example flash memory) to store the data collected from dummy in case of the batteries become disconnected. We use serial communication in data transmitting from data logger to PC. We set the serial port baud rate as 38400. The length of wire between data logger and PC should less than 2 meters, so we can get high quality data from dummy. Dummy sensors should be calibrated carefully for getting exact force data.

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VISUAL FREQUENCY FEEDBACK AND ITS EFFECT ON WHEELCHAIR PROPULSION KINETICS

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ABSTRACT

The purpose of this research paper is to determine if stroke frequency could be reduced by the use of visual feedback. Stroke frequency is the number of times a manual wheelchair user pushes on the pushrim per second. Visual feedback was used to display stroke frequency and velocity in real time so that the subject in a wheelchair observes immediate feedback on a computer screen. Subjects propelled with a significantly ($p < 0.01$) lower stroke frequencies when visual feedback was used. A lower stroke frequency may lead to more efficient propulsion and could theoretically reduce the risk of upper extremity repetitive strain injury.

INTRODUCTION

A high percentage of manual wheelchair users experience shoulder and wrist pain.[1,2] Previous studies have shown that high repetitive forces on the upper extremity can lead to carpal tunnel syndrome (CTS) and damage to the rotator cuff.[2,3] Pain and injury have been found to correlated with the frequency of a task. This project attempts to reduce the frequency of propulsion by two methods: 1) a simple statement that they should attempt to push with long strokes and few repetitions and 2) by providing constant visual feedback on the frequency of their propulsion. We hypothesized that constant visual feedback would provide a stimulus necessary to lower frequency more then just the simple statement. Findings consistent with our hypotheses could theoretically prevent repetitive strain injuries in wheelchair users in the future.

INSTRUMENTATION

The rear wheels used in this project were two SMART^{wheels}. The SMART^{wheels} measure the three-dimensional moments and forces applied to the pushrim through three strain gage instrumented beams. These forces and moments are converted from analog to digital signals using an HC11 microcontroller on board the SMART^{wheels}. The digital signal is sent through a serial port to a desktop computer.

Data were collected through the serial communication port and a program was written using LabVIEW (National Instruments v5.1) to separate the bit stream into channels and display them in real time. The SMART^{wheels} also measure angular position with respect to the initial reference frame. The change in this position multiplied by a conversion constant divided by the change in time equals velocity in MPH. The stroke frequency was obtained by taking the average of all three radial forces and comparing it to a threshold force. If the average force rises above the threshold, then the program increments a counter that records the number of strokes. The elapsed time between these increments was inverted and displayed in real time as "Stroke Frequency". The collected data were analyzed using MATLAB (Mathworks, Inc.). The MATLAB program calculated the mean velocity and mean stroke frequency as well as the *distance per stroke*.

PROCEDURE

Ten able-bodied subjects participated in the study. We choose these subjects without disability to specifically check the effect of the intervention on a new wheelchair user. The manual wheelchair was anchored onto a dynamometer, which is a platform with rollers. Each subject performed four trials. The first two trials were the control trials where the subjects were asked to maintain the specified speed of 2 MPH (0.9 m/s) and then 3 MPH (1.3 m/s). The two control trials only displayed the velocity graph and not the stroke frequency graph. All subjects were specifically told to propel using long, low frequency strokes while maintaining the target speed. The next two trials were the experimental trails and were the same as the first two except that they included the visual frequency feedback. The subjects were informed to maintain the specified speed while keeping the stroke frequency bar graph as low as possible. The data from the control trials were compared to that of the experimental trials using a paired t-test at α level of 0.05.

RESULTS

The stroke frequencies of the experimental trails were significantly lower than the control trials (See Table 1.). The average stroke frequency of the experimental trails was 45% lower at 2 MPH and 41% lower at 3 MPH than the control trials. In addition, the distance traveled per stroke was longer with the visual feedback. A significant difference in velocity was seen at 2MPH with the subjects going faster in the experimental (with frequency feedback) condition. Despite going faster subjects still pushed with a significantly low frequency.

Table 1

N=10	Speed @2MPH		Speed @3MPH	
	No Visual Feedback	With Visual Feedback	No Visual Feedback	With Visual Feedback
Stroke Frequency (Hz)	0.96± 0.34	0.52± 0.18	0.97± 0.21	0.57± 0.13
Distance/Stroke (ft)	1.47± 0.53	3.04± 0.96	2.10± 0.18	3.41± 0.86
Velocity (MPH)	1.85± 0.14	2.13± 0.29	2.85± 0.23	2.74± 0.37

Significantly differences ($p < 0.05$) were seen in all variables at both speeds with the exception of velocity at 3MPH.

DISCUSSION

As shown in Table 1, stroke frequency decreased while distance/stroke increased for both cases with the visual feedback. The subjects used less frequent and more powerful strokes when using the feedback. Nine of the ten subjects propelled at a lower frequency with the visual feedback. The frequency seen in this study without feedback is the same compared to another study that measured the characteristics of propulsion for wheelchair users with paraplegia.[4] The average velocity and distance per stroke were both higher for the subjects with paraplegia. (3.4 MPH and 5.0 feet compared to 2.85 MPH and 2.1 feet) These subjects were more efficient because they are experienced manual wheelchair users. Their force is efficiently directed in the constructive tangential direction. Also, paraplegics acquire longer stokes which produce more work. We believe this feedback system would help experienced wheelchair users in addition to new wheelchair users in reducing injury.

CONCLUSIONS

The findings of this study indicate that when this device is applied to beginning and possibly experienced manual wheelchair users it may help reduce the frequency of repetitive force on the shoulder and wrist. Future studies should be conducted to determine if this type of apparatus would provide feedback to the user, thus changing the stroke frequency and preventing CTS and/or damage to the wrist and shoulder structures. In the future, this device could be mounted to a manual wheelchair in the same way that some automobiles have on-board computers to display instantaneous gas mileage to help you drive more fuel efficiently.

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THE DEVELOPMENT OF HANDY 1, A REHABILITATION ROBOTIC SYSTEM FOR THE SEVERELY DISABLED

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ABSTRACT

The Handy 1 is a rehabilitation robot designed to enable people with severe disability to gain/regain independence in important daily living activities such as: eating, drinking, washing, shaving, teeth cleaning and applying make-up [1], [2]. The Handy 1 system has the capability to assist many disability groups to gain added independence including: cerebral palsy, motor neurone disease, muscular dystrophy, multiple sclerosis, stroke and degenerative illness of the elderly [1]. This paper will chart the development of Handy 1 and the user input.

HANDY 1 DEVELOPMENT

The Handy 1 was developed by Professor Mike Topping in 1987 to enable his 11-year old neighbour with cerebral palsy to eat unaided. The system has been continually developed over the last decade and has now assisted more than 150 people.

The main Handy 1 system (fig. 1) assists disabled people to eat and drink without the constant assistance of a carer. This enables the user to eat at their own pace and to choose the order in which they select the food on their plate [1].

Fig.1 The Handy 1 system

User Control Characteristics of Handy 1

A scanning system of lights designed into the tray section (fig.2) of Handy 1 allows the user to select food from any part of the dish. Briefly, once the system is powered up and food arranged in the walled columns of the food dish, a series of seven lights begin to scan from left to right behind the food dish. The user then simply waits for the light to scan behind the column of food that he/she wants to eat, and then presses the single switch which sets the Handy 1 in motion. The robot then proceeds onto the selected section of the dish and scoops up a spoonful of the chosen food and presents it at the users mouth position. The user may then remove the food at his/her own speed, and by pressing the single switch again, the process can be repeated until the dish is empty. The onboard computer keeps track of where food has been selected from the dish and automatically controls the scanning system to bypass empty areas [3].

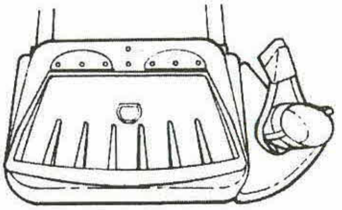

Fig 2 Handy 1 Eating tray section

During the early Handy 1 trials, it emerged that although the Handy 1 enabled users to enjoy a meal independently, however the majority stated that they would also like to enjoy a drink with their meal. Thus the design of Handy 1 was revised to incorporate a cup attachment (fig.3) [3]. The cup is selected by activating the single switch when the eighth LED on the tray section is illuminated.

Fig. 3 The cup attachment

Handy 1 food dish

A new plastic dish was developed in 1995 with seven integral walls. The dish dramatically improved the scooping performance of the robot with even the most difficult of foods such as crisps, sweets, biscuits etc. The reason for this improvement was due to the inclusion of the walled columns which ensured that the food could not escape when the spoon scooped into it. This resulted in a significant improvement. We carried out a comparison study to compare the new dish with the previous 'unwalled' dish. 22 foods were used in the study selected from 5 groups, 'vegetables', 'meals', 'desserts', 'junk foods' and 'fruits'. The study showed that the Handy 1 performed more successfully with food of all types when used in conjunction with the new walled dish. Improvements to the robots scooping performance were observed particularly with some food types such as peas, where the successful pickup rate rose from 34% to 73% [3].

As with all Handy 1 attachments, the system does not actually perform the activity for the user i.e. the robot does not actually feed the user. The user sits in an upright position and then is required to move their head very slightly forward in order to remove the food from the spoon. We have found that the fact that the user is in full control of the system and actually performs the activity for themselves helps to boost morale and self-esteem rather than if they sat passively and let the robot do the activity for them. We have especially found this to be the case with the make-up and games attachment prototypes.

Make-up application and Leisure type activities

After the initial success of the eating and drinking system we conducted surveys to determine what other activities the users would like the Handy 1 to perform. Based on positive feedback from a questionnaire sent to one hundred ladies with motor neurone disease who stated that the activity they most wished to regain was applying their own cosmetics. In many cases the ladies commented that carers were unable to apply their makeup exactly to their taste and subsequently this resulted in a feeling of frustration and loss of self esteem.

Work commenced on a Handy 1 makeup attachment designed to enable ladies to choose from a range of different cosmetics including blusher, foundation, eye shadows and lipsticks. A prototype system was completed in 1996 and successfully trialled with a number of ladies with motor neurone disease (fig.4). Briefly the system works as follows, when Handy 1 is powered up a series of lights adjacent to each of the cosmetic types begin to scan, one after another, the concept being that when the light is lit adjacent to the cosmetic that is required, the user simply activates the single switch. At this point the Handy 1 selects the correct brush or applicator and applies the correct amount of blusher, foundation, lipstick, eye shadow etc. Once the make-up has been applied to the applicator it is then taken by the robot to the appropriate face position where the user is able to apply the make-up [4].

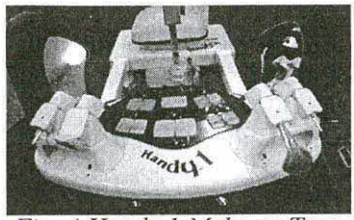

Fig. 4 Handy 1 Make up Tray

Following a survey conducted at the Motor Neurone Disease Association AGM. Many of the disabled people whom we have spoken to have expressed that they don't have many activities with which they can occupy their leisure time and so they said that they would appreciate the development of some leisure type activities. Following the study a pre-prototype version of the Handy Artbox was developed to enable severely disabled people to paint and draw unaided. This was successfully evaluated in a special school and was found to have potential within the classroom [5]. A Handy 1 games attachment incorporating the 'Connect 4' game has also been developed. One lady with multiple sclerosis tried it over a Christmas period and commented that it was lovely to be able to actively play with her grandchildren rather than be on 'on-looker'. All attachments are operated with the usual scanning lights and single switch control.

CONCLUSION

The necessity for a system such as Handy 1 is increasing daily, the changing age structure in Europe means that a greater number of people with special needs are being cared for by ever fewer able bodied people.

The simplicity and multi-functionality of Handy 1 has heightened its appeal to all disability groups and also their carers. The system provides people with special needs a greater autonomy, enabling them to enhance their chances of integration into a 'normal' environment.

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AVAILABILITY, PROVISION, AND SUPPORT OF ASSISTIVE TECHNOLOGY BY POSTSECONDARY INSTITUTIONS

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ABSTRACT

Assistive technology offers a continuum of potential solutions for postsecondary students whose functioning is limited by physical, sensory, or cognitive impairments. The purpose of this study was to develop a descriptive profile of the availability, provision, and support of devices and services at postsecondary institutions in the United States. A survey of a national sample of disability service providers at two-year and four-year colleges and universities explored issues related to procedures and practices, accommodations, access, availability of assistive devices, service delivery, and resource utilization.

BACKGROUND

In the past twenty-five years, there has been a significant increase in the enrollment of students with disabilities in postsecondary institutions. The expansion of community colleges, changes in admission requirements and policies, and the establishment of disability support services on college campuses have helped to fuel the rise in freshmen reporting a disability to more than 140,000 students (1).

Exemplar technology support programs, identified in the literature (2), represent only a small sampling of efforts made by two-year and four-year colleges. A review of the literature identified only two published studies conducted to examine computer accessibility (3)(4). In both instances, the researchers concluded that the availability and use of assistive technology varied among institutions with significant differences between two-year and four-year schools. With these few exceptions, there seems to be a scarcity of information documenting how postsecondary institutions are support and provide assistive technology for students with disabilities and the strategies they have used to overcome barriers.

RESEARCH QUESTIONS

This study addressed questions related to accommodations and access, service delivery, resource utilization, procedures and practices, and equipment availability among postsecondary institutions.

1. What procedures or guidelines are in place to determine the provision of reasonable accommodations and auxiliary aids?
2. What accommodations are provided to students with disabilities by post-secondary institutions?
3. What assistive technology devices and services are provided to students by post-secondary institutions? What assistive technology devices and services are considered to be the student's responsibility?
4. What percentage of self-identified students with disabilities submits specific requests for provision of assistive technology? What percentage of students requires evaluation of assistive technology needs?
5. What funding sources and other organizational resources are used by post-secondary institutions to acquire assistive technology devices and services, including evaluation, provision of devices, training for students, orientation and training for faculty, set-up and follow-up, and equipment maintenance?
6. What problems or barriers are identified which impede the provision and use of assistive technology in post-secondary institutions? What solutions or strategies have been employed to overcome problems associated with provision of assistive technology?
7. What is the prevalence and administrative arrangement for assistive technology support programs among postsecondary institutions.

METHOD

In the absence of a previously developed instrument, a survey was developed to collect information and answer the questions posed by the study. The survey instrument was refined through a review by experts in the assistive technology and special education fields. The content of the survey instrument was based on issues identified in an extensive review of the professional literature. Some items were drawn from previous surveys related to this topic. The survey instrument was divided into six parts: accommodations and accessibility, assistive technology devices and services, assistive technology support programs, funding, barriers to provision of assistive technology, and demographics. The demographic characteristics related to size, location, status as primarily residential/commuter, public/private, Carnegie classification, and the incidence of disability categories represented in the student body were also considered.

The respondents for the survey were disability service providers at public and private postsecondary institutions in the United States. A stratified systematic sample was drawn from institutions listed in the Classification of Institutions of Higher Education (50. Survey distribution was by postal service mail with follow-up to promote an adequate response rate. Of the 582 mailed surveys, 304 (52%) were returned and analyzed.

RESULTS

The majority of institutions represented in this study (72%) indicated that between one nad four percent of students enrolled in their institution have declared a disability. Consistent with estimates of disability incidence in the literature, students with learning disabilities comprise the largest group of disabled students.

Most institutions reported having installed adaptive computer equipment in at least one location, however, universal access across campus facilities and network services was not indicated. Participants indicated significant variability in the availability of a continuum of low- and high-technology devices including text generation and output technology, organization and time management tools, augmentative communication devices, environmental control units, mobility aids, and transportation and environmental access technologies. Concomitant issues related to device complexity, function, cost, and familiarity appeared to influence the availability of devices listed in the survey. Significant differences were found among institutions in the provision of assistive technology services involving evaluation, training for users and providers, follow-up support, maintenance, and dissemination of information about new assistive technology developments. Forty-nine of the participating institutions (20.9%) indicated the existence of an established assistive technology program.

Respondents confirmed the existence of several barriers including, funding, training, internal cooperation, and the availability of expertise. Funding represented the most significant challenge confronted by participating institutions. A majority of institutions reported multiple internal and external funding streams for financing assistive technology. Resources other than direct funding, such as alliances among institutional units and administrative support, also contribute to effective service delivery. The consensus of opinion from respondents representing all types of institutions highlighted the importance of collaboration and partnerships internal and external to the organization.

DISCUSSION

The Americans with Disabilities Act and Section 504 of the Rehabilitation Act of 1973 require that accommodations and auxiliary aids and services (e.g., assistive technology) be considered on a case-by-case basis to give students the opportunity to succeed at a rate similar to non-disabled peers. Consideration of individual need was emphasized in comments added throughout the surveys. In situations where students with disabilities are few in number and resources are scant, the available accommodations or aide seem to be tied to a specific student request. In general, responses to the survey suggest that many institutions tend to maintain a responsive mode in providing devices and services. Institutions with larger student enrollments, greater student diversity, and established funding arrangements take a more proactive approach. These larger institutions are also more likely to demonstrate a commitment to campus-wide adapted access and technology availability. Not surprisingly, institutions with established assistive technology programs are the most likely to provide services and least likely to report barriers associated with provision and support.

Results from this survey corroborated with the current literature and point to the importance of concerted efforts by postsecondary institutions to examine and address the critical issues related to assistive technology.

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THE DEVELOPMENT OF AN INTELLIGENT CUEING DEVICE FOR USE BY PEOPLE WITH DEMENTIA DURING ACTIVITIES OF DAILY LIVING

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ABSTRACT

An intelligent cueing device that can be used to assist people with dementia during activities of daily living is being developed. The device uses artificial intelligence to "watch" the user and his/her surrounding environment, learn from his/her actions, adapt to individual preferences, and issue varying levels of cue detail. This paper will focus on the rationale behind this research, and progress of the device's development.

STATEMENT OF PROBLEM / RATIONALE

It is estimated that one out of three people in Canada over the age of 85 has a moderate to severe dementia [1]. Dementia is characterized by a decline in cognitive function and memory. This often results in a person not being able to complete activities of daily living (ADL) such as using the toilet, or washing their hands, because he/she may become disoriented and confused. The current solution is for a caregiver to constantly supervise and assist the person using verbal prompts. This loss of autonomy and independence often results in the person becoming agitated and embarrassed.

It is thought that this independence can be improved through the use of an intelligent, computerized device that provides the reminders needed by the user, and monitors his/her progress. Thus, assistance is provided but a caregiver is not required to be present. This paper describes the progress of the development of such a device for people with dementia.

BACKGROUND

Several computerized cueing devices and memory aids have been developed and tested for simple and complex tasks, such as assisting a person while shaving, and guiding a person through vocational tasks [2, 3, 4, 5]. These devices were proven to be efficacious, but none of them were used with people with dementia, nor was artificial intelligence (AI) used.

In a pilot study performed by the authors, it was determined that a person with dementia will complete a task in response to a computerized device that used a recorded voice for cueing [6]. The simple computerized cueing device, which did not use AI, monitored and prompted subjects with severe dementia through handwashing. Using a single-subject research design (SSRD), it was observed that the subjects were able to independently complete (i.e. without a caregiver) approximately 25 percent more tasks when the device was used [6]. These results provided sufficient evidence that a computerized cueing device can be effective, however, it also showed that future devices need to be more intelligent to assist a person better. This study has prompted the next stage of this research, developing a more intelligent device using AI.

Artificial intelligence (AI) techniques are algorithms that could be used to design a computer program that acts more like a human when it completes various cognitive tasks such as decision-making, or task guidance [7]. Two specific AI algorithms are applicable to this cueing device design. Given a set of tasks, a **plan recognition algorithm (PRA)** will find a plan that explains the actions of the user [7]. This plan, and its associated tasks, can be used to guide the user until the goal is met. An **artificial neural network (ANN)** learns "associations" between input and output data patterns by first learning the correct associations for a set of training data. It can then be used to classify new data into pre-learned categories [7].

DESIGN OBJECTIVE

The objective is to create a device that makes use of AI and other sophisticated programming techniques, to guide a person with dementia intelligently and rationally through any ADL task.

DEVELOPMENT

The device will consist of a hardware component that tracks the actions of the user, and a software component that analyzes these inputs and makes decisions. Software has been under development for several months, while hardware development has just commenced.

There are three main modules in the software—the ANN, the PRA, and the Action module (AM). These three modules were programmed using Matlab v.5.3 [8]. The modules are vector-based, which allows normally complex operations to be completed with more ease and speed than a non-vectored algorithm. A vector, or a particular element of one, defines all events, inputs, and records. For example, all of the verbal cues were assigned cue identification numbers when they were recorded. When the device needs to determine if a particular cue had already been played to the user, a simple search of a vector, whose elements are the already issued cues, then occurs.

After the hardware acquires input, the first module, the **ANN,** is invoked. The ANN is a probabilistic neural network, which uses probability theory to "learn" which tasks correspond with the various inputs from the environment. The network classifies the inputs into task identification numbers. A pre-existing algorithm for this type of ANN with some modifications was used. An ANN was used because it can accurately classify inputs that may have never been seen before by the device, it allows for easy on-line training of the device for any ADL, and never seen before inputs and task identification numbers can be added fairly quickly.

The next module is the **PRA**. Using the output from the ANN, it determines which plan the user is completing by comparing a vector that keeps track of the steps already completed, with a pre-existing database of possible plans that could be executed. This database contains several row vectors. Each vector constitutes a plan, and is a different sequence of task identification numbers. The first element of each vector identifies the plan identification number. This algorithm uses vector searches to find the step vector within one of the database's plan vectors. If a match can not be found, the algorithm will attempt to predict which plan the user is attempting. This is done by removing the most recently added step to the step vector one at a time until a match can be found.

The final module is the **AM**, which is responsible for selecting and playing a pre-recorded verbal prompt only when indicated by the PRA. An individualized cue history is used to select the required level of detail for the issued prompt. The cue history is a file that contains a column vector. Each element of this vector corresponds to a different task, and indicates which level of cue detail to issue. This history is constantly updated to reflect the most recently successful cueing strategy for the user. Once the cue detail level is selected, the associated cue is played using a 16-bit soundcard that is connected to a speaker hidden in the user's environment.

The actions of these modules, progress of the user, and other parameters are displayed using a graphical user interface (GUI) that was programmed using LabVIEW v.5.1 [9]. The GUI and the data from the Matlab modules are linked together using dynamic data exchange functions in Labview.

The primary objective of the hardware development is to select, or design, a system that will allow the device to "know" what task the user is completing. Various on-person tracking devices and environmental switches are being used with the developed software to determine their efficacy.

SUMMARY OF DEVICE FEATURES

The following is a summary of the current primary device functions:

- Can monitor and report the progress of a user
- Can issue a verbal prompt to a user only when necessary
- Can issue varying levels of cue detail for each task
- Can adapt to individual cueing strategies
- Can adapt to user's preferences with respect to varying plans
- Can be easily trained on-line for any ADL.

FUTURE DEVELOPMENT

The next steps in development are to:

- Develop/select an accurate, reliable, and generalizable monitoring system
- Add speech recognition capabilities to the software
- Re-design the AM to make it more intelligent
- Improve the overall look of the GUI and the user-friendliness of the device.

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SIGN LANGUAGE INTERPRETATION OVER AN INTERNET 2 NETWORK

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ABSTRACT

Two series of experiments involving video conferencing equipment, high-speed networks, and sign language interpreters were carried out at the Supercomputing 99 (SC99) conference in Portland, Oregon. The first series of experiments were designed to assess the feasibility of delivering American Sign Language (ASL) interpretation services for conference presentations from a remote location. The second series of experiments were designed to assess the feasibility of providing remote "interpreter-on-demand" services to a conference attendee who is deaf. This paper describes the events surrounding the planning and implementation of these experiments.

BACKGROUND

Traditionally, certified interpreters provide in-person sign language interpretation services. However, in some locales there is an insufficient number of interpreters to meet the demand for service. Video conferencing technology holds promise for reducing barriers to interpretation services. Video conferencing technology can eliminate the time that interpreters spend traveling to a site to provide services, leading to a cost savings and potentially to greater availability of interpreters. Video based interpretation can be used to provide interpretation for as little as a few minutes at a time. Using video conferencing technology it would also be possible to hire interpreters from anywhere in the country, including interpreters with expertise in a particular discipline.

Sign language interpretation involves rapid hand, arm and finger movements as well as changes in facial expressions and lips. In order to be effective, remote video interpretation requires a connection between sites that provides a guaranteed minimum continuous bandwidth. As more people and businesses connect to the Internet, it would seem to make sense to deliver this service over the Internet. However, despite the advantage of widespread Internet access, even companies that have high-speed connections to the Internet cannot guarantee that the required bandwidth will be available when needed continuously throughout a session.

In 1996 a group of government agencies, companies and research universities began development of what is known as the Internet 2 (I2). Collaborators working on the I2 are developing the next generation of Internet applications and networks. Currently, the networks deployed as part of the I2 provide bandwidths much greater than those available over the Internet. Thus, the very high performance Backbone Network Service (vBNS), an I2 network with connections at the University of Wisconsin-Madison and SC99, served as a test bed for this project.

OBJECTIVE

The two primary objectives for this project were to 1) demonstrate to the high performance computing community the potential application of high-speed networks for the provision of remote sign language interpretation and 2) to develop an understanding of the technical issues surrounding the provision of remote sign language interpretation over the I2 and over wireless networks.

APPROACH

There was a desire on the part of the project team to use off-the-shelf, non-proprietary or low cost technology. The project team tested various hardware configurations that were compatible with Microsoft NetMeeting 3.01 and Sorenson VisionLink 2.0, two video conferencing software applications. Informal pre-conference tests suggested that NetMeeting would provide better quality video transmissions over the vBNS. Thus, the majority of the experiments were carried out using NetMeeting.

In the final implementation, the remote site where the sign language interpretation originated, used a Pentium II, 400MHz, 128M RAM, desktop with a Winnov Videum PCI capture card, a Toshiba video camera and Microsoft's NetMeeting 3.01. A 10M switched Ethernet network was in place at the remote site. The computer at the conference site was a Pentium II, 366MHz laptop with 64M RAM. A 100M switched Ethernet network was in place at the convention center.

Series 1: Keynote and Plenary "Experiments"

The audio portion of the keynote and plenary sessions was patched into the convention center phone system and sent to the remote site via standard telephone lines in order to avoid potential transmission delays introduced by NetMeeting. The interpreter at the remote site listened to the presentation on a speaker phone and signed the session while seated in front of the video camera. The image of the interpreter was sent back to the convention center via the vBNS and projected onto a screen. Three, two-hour sessions were interpreted in this manner. Although no direct measurements were possible with the setup in place, it was estimated that frame rates of 20-25 per second were being attained. While this frame rate provided video quality sufficient for one-way interpretation, there were still occasional momentary freezes in the image that degraded content.

Series 2: Wireless "Experiments"

In the wireless experiments, a member of the research team who is deaf used an "interpreter-on-demand." He carried a Sony PictureBook minicomputer with a wireless network connection as he roamed around the convention center. A small microphone taped to the side of the PictureBook picked up the speech of someone nearby and sent it to the remote interpreter via NetMeeting. The interpreter's image was transmitted over the wireless network and displayed in an adjustable size window on the PictureBook. This setup worked well as long as full duplex audio was disabled in NetMeeting.

Tests were also carried out to see if the wireless system could provide the researcher with ASL support during a conference presentation. A wireless assisted listening device (ALD) was used to pick up audio from the speaker and feed it into the PictureBook. Since the PictureBook had a built in camera, the user could also sign back to the interpreter if necessary to confirm a sign or request clarification.

A final set of tests was carried using a head mounted display (HMD). With this configuration, the researcher viewed the interpreter's image through the HMD, allowing him to view the presenter, presentation screen and the interpreter simultaneously.

DISCUSSION

SC99 provided the project team with an excellent venue for experimentation. The remote sign language interpretation of the keynote and plenary addresses provided the high performance computing community with a visible demonstration of how high-speed networks can provide important services directly to individuals with disabilities. Feedback from the member of the research team who uses sign language and the interpreters who were present at the SC99 sessions indicated that the remote interpretation was of sufficient quality to convey the content of the sessions.

These experiments were feasible, in part, due to the bandwidth capacity of the vBNS. Even though the vBNS provides bandwidths in the 622 Mb range and the setup used to provide remote interpretation only required approximately 500 kb, occasional freezes still occurred. Thus, high bandwidth alone is not sufficient to support remote interpretation. The project team plans to investigate the compression and buffering algorithms used in applications such as NetMeeting, as well as look into network monitoring tools that may help explain the momentary image freezes experienced during sessions. In addition, more advanced head mounted displays will be tested.

The interpreters at the remote site provided additional valuable feedback. They would have liked to see the layout of the session room, the presenter's slides, and the presenters themselves. The interpreters also noted that the setup used in the keynote and plenary sessions did not allow any feedback from the participant who was using the service. The wireless experiments did allow two-way ASL communication.

By working with research programs internationally, the goal is to eventually create mechanisms for combining automatic computer speech recognition and translation technologies with human assistance when and where needed to yield low cost text and sign language "translation on demand." Even before these types of devices can become a standard tool, "pop-up interpreter" windows could be built into standard browsers so that wherever there was a browser, there could be an interpreter whenever one was needed.

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HOW DOES HE LOOK: TRACKING AUTISTIC GAZE

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ABSTRACT

Images of faces and objects were presented in a virtual reality display, and recognition memory was then tested. Point of gaze was tracked using a camera installed in the VR headset. These data (one individual with autism and two controls) were collected to assess feasibility of a forced-choice response. The primary hypothesis of the study is that individuals with autism willdiffer from controls by failing to attend to the most informative, eye area of the face, and by scoring more poorly on faces than objects. Accuracy scores for all three participants ceilinged, indicating that a forced-choice response format is insensitive to the phenomena of interest. Visual examination of videotapes of the eye-tracking superimposed on the images support the hypothesis, and the data await detailed analysis. An unexpected, large effect was observed: the experimental participant's gaze consisted of disproportionately more movement and less fixation in comparison with control participants. Implications for further investigation and intervention are discussed.

BACKGROUND

Autism is a severe, lifelong, developmental disability characterized by three core areas of deficit: marked impairment of social interaction, language that is at best odd and at worst absent, and repetitive behaviors and intense, narrow, sometimes highly idiosyncratic preoccupations (e.g., train schedules, or washing machines) (1). While there are interventions that are helpful to some, the benefits are usually minor in relation to the profound deficits (2).There is considerable interest in characterizing the cognitive underpinnings of autism, in order to develop effective interventions.

RESEARCH QUESTION

The experiment is based on the hypothesis that failure to acquire typical face-processing in infancy plays a key role in the development of autism. Early infancy, before vision has developed beyond the processing of high-contrast, low-spatial resolution images, before the infant is able to modify his environment by acting on it manually or moving to another location, and while he remains dependent on frequent, socially rich care-provision by parents, is an optimal time for acquisition of nonverbal gaze communication. It is suggested that infants who for various reasons fail to acquire face gaze during this period may have taken the crucial step along the autistic developmental pathway, as social, communicative and typical behavioral development may be dependent on nonverbal communicative channels (3). This hypothesis, and a literature that has provided mixed but largely supportive evidence of atypicality of recognition of faces and of facial expressions of emotion by persons with autism, suggest that eye-tracking studies of autistic gaze would be informative. A second prediction is that persons with autism would be expected to score more poorly on faces than on non-social objects, relative to controls.

METHOD

Data are presented here from three participants: one individual with autism and two non-

disabled controls. The individual with autism was a 22-year-old man who had completed basic high school requirements in a special education classroom, and five months of vocational readiness training. Control Subject 1 (C1) had completed one semester of a master's program in addition to college, and C2 had completed two years of auto mechanics training after high school.
Stimuli to be remembered were exposed for 4 seconds each, separated by a pause during which a small square target was displayed on which participants were to fixate while awaiting the next stimulus. Participants were told that this was a task of remembering faces and objects. They would be shown pictures of faces and objects one at a time. After they had seen one block of stimuli (8 images) they would be shown pairs of stimuli, consisting of one image already seen and one not yet seen. Their task was to say whether the image they had seen before was on the left or on the right. Point of gaze was tracked throughout the performance of the task. A five-point calibration routine was carried out, accuracy was then tested against a grid of 12 points labeled with letters and numbers, and calibration was redone if necessary. The calibration check was repeated after each block of stimuli was displayed and tested. If participants took a break during which the headset was removed, it was of course necessary to recalibrate. ISCAN tracks the pupillary center and the corneal reflection. Occasionally, because of individual differences in facial structure, such as eyelid protrusion, tracking is unsuccessful. There is also the possibility of artifacts, for example occasionally the eyelid reflection is tracked instead of the corneal reflection. Data were reviewed and points that were physiologically unlikely (i.e., that implied a velocity of >700 degrees of angular movement per second) were removed. Fixations were defined as sequences of data points covering at least 100 ms. with less than +/-.5 degrees of variation (Rizzo).

RESULTS

Number of attempts required to achieve successful calibration differed across individuals. Participants C1 and A were relatively quickly calibrated, while it required several attempts to calibrate participant C2. The complete set of 4 blocks (32 stimuli and 32 forced-choice pairs) was carried out by C1 and A; however the data for A's Block 1 had to be discarded as the calibration test showed that tracking had become inaccurate, apparently due to movement of the headset caused by A's scratching his nose. C2 completed Blocks 1-3, and then experienced dizziness, which resolved when the headset was removed. Participants also differed in the total number of data points obtained: C1 and C2 averaged 218 and 205, respectively, out of 240 possible points per stimulus (4 seconds, 60 points/sec). A1 averaged 178 points. While tracking continued throughout the experiment, there was sometimes failure to track one or both of the two images (corneal reflection and pupillary center) required to return a point, e.g., during blinks and when a lowered eyelid obscured the eye.

Figure 1: % Time Spent in Fixation

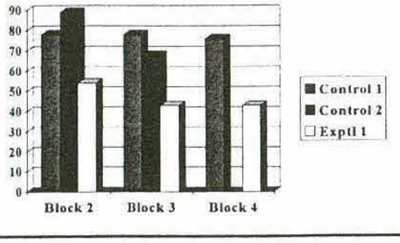
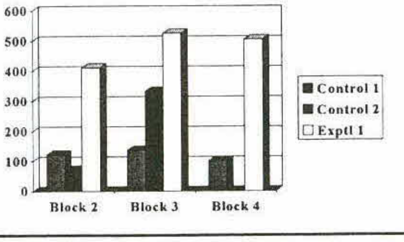


Figure 2: Mean Angular Distance Traveled



No differences in recognition accuracy were noted, across individuals or across categories. In these trials, participants were offered a 'forced choice' response. They were shown the previously displayed image next to a foil which resembled it (e.g., the target chair had another chair as its foil; a female face with long blond hair and a neutral expression was paired with a foil that was also female, with long blond hair and a neutral expression). Even for the individual with autism, who had scored much more poorly in an earlier test relative to a control, when yes or no responses to single images were required, forced choice was very easy.

DISCUSSION

The focus of this study was intended to be on 'where' autistic gaze was directed. Examination of the data, however, pointed to an additional phenomenon, 'how' the individual with autism viewed the stimuli. In contrast to the control participants, A1 usually spent less than half his time fixating, and moved his gaze in a rather disorganized way around and beyond the image on the displays. Since there is no visual intake during saccades, the young man with autism was 'seeing' the images only about half the time they were displayed, or less.

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USE OF "THERAPIST-FRIENDLY" TOOLS IN COGNITIVE ASSISTIVE TECHNOLOGY AND TELEREHABILITATION

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ABSTRACT

A "therapist-friendly method of customizing cognitive assistive technology was used to help a patient with persistent cognitive, motor, and language deficits following a brain injury gain independence in specific priority activities. Prosthetic software was designed by a multidisciplinary team of clinicians and a computer programmer, enabling each intervention to match the specific abilities and deficits of the patient. Telerehabilitation technology and techniques were used to efficiently deliver all therapy and technical interventions in the patient's home. The results demonstrate a significant increase in functional independence for the patient after a minimal amount of training.

BACKGROUND

A characteristic of cognitive assistive technology is that it is highly customizable. That is most efficiently done if the therapist plays the major role in prosthetic software design. It must be customized to the specific abilities and deficits of the individual, focus on the patient's priority activities, be developed in the environment in which the activities will be performed, and be user-friendly to the patient (1). Additionally ongoing evaluation is necessary as the patient uses the technology in daily activities, making modifications as necessary (2).

Recently the delivery of therapeutic interventions at a distance using electronic means and remote monitoring of rehabilitative progress known as telerehabilitation has been recognized (3,4). A computer-based platform of telerehabilitation has been developed that enables cognitive assistive technology to be designed and implemented in a more efficient and successful manner than traditional forms of service delivery (5).

METHOD

The Telerehabilitation Approach

Treatment sessions were conducted using a computer-based telerehabilitation method. The patient was provided with a personal computer and video-communications technology in his home. The therapist had a similar system with some additional software and networking capabilities. This platform is comprised of four components: 1) videoconferencing between the patient in his home and the therapist in her office; 2) remote computer connection, allowing the therapist to share the patient's home computer from her office; 3) data collection, providing the therapist with work products and detailed logs of the patient's use of the technology; and 4) an integrated treatment planning system that coordinates activities of the therapist, patient, and computer programmer.

A clinical team conducted 3 telerehabilitation treatment sessions per week with the patient. Treatment sessions generally focused use of the assistive technology to facilitate greater independence. When new features or applications were introduced to the patient, usability testing and training activities were also incorporated. In addition to direct treatment time, the occupational therapist reviewed patient work products and the patient's activities performed on the computer. As new features and applications were developed for the patient, the therapist also devoted time to design planning and testing sessions.

Patient Characteristics

SH is a 41-year-old man who sustained a severe brain injury three years ago. He underwent an extensive period of inpatient and outpatient therapy, when he was referred to this program he was no longer receiving therapy services. Residual deficits included verbal apraxia, left hemiplegia, right apraxia, and cognitive deficits in the areas of memory, sequencing, generalization, and problem-solving. A personal care attendant assisted him with dressing, bathing, and meal preparation. His mother, with whom he resided, managed all of SH's finances, appointment scheduling, and many health care management activities. SH maintained an active social life, travelling into the community using transportation services which were scheduled by his mother.

SH was not able to communicate through handwriting due to ataxia, but was able to type using a standard keyboard. He had a simple communication device, but due to cognitive deficits, was not proficient to use many of its features. He was able to type short phrases and have them spoken aloud, but he could not store and modify longer lengths of type.

Defining the Problem

After an initial evaluation, he was provided with a simplified word processor to record his thoughts and answers to the therapists' questions. Details about functional problems were acquired through review of the patient's journal, interview, and performance observation using videoconferencing. Three identified functional problems are the focus of this presentation.

1. Relaying detailed information to his physicians during medical appointments
2. Calling to schedule rides from handicapped transportation services
3. Communicating socially in greater depth with his friends

Designing the Intervention

The therapist has a toolkit for design and some implementation of prosthetic software. Some technical details are left to the programmer. Prosthetic software interventions aimed to enable independence in performing the activity in consideration of his specific abilities and deficits. Usability of the designed interventions with the patient was conducted by the therapist, during which suggestions from the patient are solicited. Interventions were modified based on results of usability testing and the patient's input. The interventions designed for this patient, relevant to the three functional problems listed above, were:

1. Simplified file access, save, and print commands for word processor to increase ability to create, access, modify, and print longer, detailed amounts of information.
2. Addition of speech synthesis function for same word processor to be used for phone call, with ability to easily select phrases of prepared text to be spoken in response to questions.
3. Addition of rolodex and envelope printing function to same word processor.

RESULTS

Relaying detailed information to his physicians during appointments

After two half-hour training sessions, SH was independent to add to and print a file that he titled "doctor information". Follow-up data revealed he modified and printed this document two times a month for his appointments. SH reported a significant increased his ability to communicate important information to his doctor. Later, he created 4 other files for similar purposes, which the data showed he regularly modified and printed in correlation with events on his calendar.

Calling to schedule rides

After two half-hour training sessions, SH was independent to use the Play/function to make a phone call and schedule his transportation. In follow-up, the data report indicated he had to repeat sentences several times, a problem the patient did not recall. The therapist contacted the operator the following day, who revealed that the information was spoken too fast for her to write it all down the first time through. Modifications were made to the intervention that added pauses between phrases of information. Follow-up data indicates he has continued to make this phone call each week.

Communicating socially in greater depth with his friends

SH began using the file and print functions he learned to type letters to his friends, but was unable to address the envelopes. An envelope-printing function was added, which the therapist customized to SH's specific abilities and deficits. SH was proficient to use this program after one half-hour training session. Follow-up data after initiating this program indicated he sent 1-3 letters each week to friends.

DISCUSSION

Several key factors of this telerehabilitation and technology design method are thought to contribute to the success of this patient treatment. First, the telerehabilitation technology allowed the therapist to work with the patient in his own environment and focus on his high priority real-life activities as opposed to simulated activities in a clinical setting. Second, the data collection facilitated communication and acquisition of detailed information from the patient and enabled the therapist to be aware of the patient's activities as he used the technology throughout the day. Third, therapist-friendly tools promoted the collaboration between the clinicians and the programmer and enabled development of assistive technology specific to the patient's abilities and needs. This detailed level of customization ensured minimal training on the part of the patient to achieve proficiency. The result was development and implementation of assistive technology that significantly improved the patient's functional independence.

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ACCESS TO WIRELESS TELECOMMUNICATIONS FOR PEOPLE WHO USE TEXT TELEPHONES (TTYs)

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ABSTRACT

Wireless telephones have become popular products that consumers value for convenience as well as for reasons of safety and security. Digital wireless telephones are not compatible with text telephones, used for telephone conversations by people who are deaf and by many people who are hard of hearing or speech-disabled. This paper describes the combined efforts of government, consumers, industry, and researchers to make these ubiquitous phones accessible.

BACKGROUND

Wireless telephones (commonly known as cell phones) are among the fastest growing technologies worldwide. In the U.S., there are more than 80 million wireless telephone subscribers, and a small but growing number of telephone customers are foregoing wireline service in favor of wireless service. Wireless technology is also being used in organizations' PBXs, so that employment prospects of people with disabilities will be affected if the technology is not accessible.

Text telephones (for historical reasons, called TTYs in the U.S.) are specialized devices used by people who are deaf, by some who are hard of hearing, and by some who have speech disabilities. TTYs share some characteristics with fax machines and modems, in that they are analog data communications equipment, but their signaling and coding of data are quite different. TTYs do not utilize a carrier tone or calling tone, and they use FSK signaling, in which a signal is put on the line only when a key is pressed. In the U.S., the default protocol for TTYs is called Baudot. It operates using a 5-bit code transmitted at 45.45 bits per second.

Analog cellular technology is being supplanted by digital wireless technology. Analog cellular technology (AMPS) is inherently accessible to people who are deaf and hard of hearing in that it presents no major compatibility problems with text telephones. (Not all analog cell *phones* are accessible, but the transmission technology presents no barriers.)

In contrast, digital wireless technology presents problems of compatibility with text telephones. Four digital technologies, known in industry vernacular as CDMA, TDMA, GSM/PCS1900, and iDEN, are in use by wireless carriers in the U.S. In order to ensure accessibility and choice of carrier, the compatibility problem will need to be solved for each of these technologies.

APPROACH

The driving force behind industry efforts toward TTY compatibility was the Federal Communications Commission. As part of a 1997 Report and Order (1) on enhanced 9-1-1 services through digital wireless telephones, the FCC ordered wireless carriers to support TTY conversations with 9-1-1. An initial deadline of October 1, 1997 was extended with the agreement of consumer representatives, in order to give industry time to develop and implement solutions.

The Cellular Telecommunications Industry Association and the Personal Communications Industry Association established the Wireless TTY Forum as a venue for discussion, information exchange, and collaboration among industry, consumers, government, and researchers. The Forum has met for approximately 20 full days since its inception in the fall of 1997. Each meeting has drawn approximately 40 participants from the various stakeholder groups. The Forum provides quarterly progress reports to the FCC.

The Rehabilitation Engineering Research Center on Telecommunications Access has been an active participant in the Forum since its inception and a staff member serves on the Forum's steering committee.

OUTCOMES

Testing. A standardized test of transmission accuracy was developed by an engineering company with input from Forum participants (2), and reviewed and modified as necessary by the industry's technical working groups for each technology. The test involved calls between a mobile handset and portable TTY to a wireline unit, in this case a computer with TTY modem for purposes of data capture. A string of random characters was sent across the link and scored by means of a software program developed by a participating company for this purpose. Results verified that, while error rates in analog were low (on the order of .5%), error rates on digital wireless links were unacceptably high, ranging from 3% up to 24% or higher. Newer GSM technology using an enhanced full-rate vocoder had the best results of the digital technologies, while CDMA had the highest error rates. (Subsequent field testing by the RERC revealed that two-way typing resulted in higher error rates than did strings of characters, so that there is some potential for underestimation of field error rates using the standardized test method.)

Connection. One challenge was the use of different methods of coupling for the two technologies. For direct connection, TTYs use RJ-11 connections, while digital wireless phones provide audio connections only, for use with hands-free adapters and other accessories. Two of the TTY manufacturers agreed to add audio jacks to their mobile TTY models to facilitate connection to mobile phones. The Telecommunications Industry Association TR.45 committee agreed to undertake a study on standardizing an interface between the proprietary audio connectors of some handset manufacturers and the audio jacks now offered on some TTYs.

Guidelines and Standards. The RERC developed a list of 13 consumer requirements for solving this accessibility problem. This list included a benchmark of 1% error rate or below on calls with reasonable signal conditions, a vibratory means of ring signaling, a visual means of line status indication, a means of alternating next mode and voice mode on a call, prohibitions against using solutions that require retrofitting the TTY network, and other requirements. The list was included in its final Order by the Federal Communications Commission as meriting consideration by manufacturers. The inclusion of this list in the Order was an extremely effective mechanism for communicating consumer needs to the industry. As a result of the Forum, the RERC also initiated action to carry a Forum contribution on the signal characteristics of TTYs into the TIA standardization process. Having an industry standard for TTY protocol will assist the wireless industry, as well as other telecommunications-industry segments in accommodating TTY in their networks.

Solutions to Transmission Error. Lucent Technologies offered the first thorough diagnosis of the problem and was the first company to offer a solution. Lucent determined that loss of bits due to frame error was the root cause. Lucent's solution (3) involves building a Baudot tone detector into the systems' encoders. Upon recognition of the signal, the tones are converted back to data. The data are transmitted through the audio path and re-modulated at the decoding end. The solution requires software upgrades both in the wireless infrastructure and in handsets. It provides for error correction, which has heretofore never been available in TTYs. It requires no special action by TTY users, and it meets all of the user requirements. The solution will be applied in at least two of the four digital technologies; other solutions may be used in the other two. Implementation will require at least 18 months.

DISCUSSION

In addition to the technical issues, there have been some interesting policy issues in this process. The FCC's requirement for providing TTY users with access to digital wireless telecommunications was placed on carriers. Carriers do not manufacture equipment. Manufacturers are the only ones who can solve problems in their technologies. This factor probably resulted in some delay in research and development, which did not begin in earnest until approximately a year after the initial (1997) FCC deadline.

Another important policy note is that these events took place outside the auspices of Section 255 on telecommunications equipment accessibility, which is somewhat limited in that companies have to undertake only that which is "readily achievable." The more stringent requirement under the E-9-1-1 proceeding made success possible. The FCC's attention to the issue has been unflagging, and this attention has made all the difference.

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RECREATION KAYAKING FOR INDIVIDUALS WITH DISABILITIES

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ABSTRACT

This case study was initiated by a 41-year young woman who enjoys recreational tandem kayaking. Michele, as a result of a car accident, suffered an incomplete C6/C7 spinal cord injury, which resulted in quadriplegia in 1981. Due to her disability, adaptations are necessary to access the equipment used in kayaking. Michele had a previous adaptation made to help stabilize her in a seated position in a kayak, but her limitations in holding and moving the paddle prevented her from fully participating in the sport. The concept and design of this product would enable Michele and others with similar disabilities to attain necessary stability and safety while kayaking.

BACKGROUND

At the age of 24, Michele was involved in a catastrophic car accident. As a result, Michele had a severe spinal cord injury that paralyzed her from the neck down. She underwent intensive physical therapy that enabled her to regain full use of her head, neck and arms. Although she still has limited use of her hands due to paralysis, her active and positive lifestyle contributes to maintaining and improving the flexibility and strength in her arms and shoulders. Michele's energetic pre-injury lifestyle gave her the motivation needed to minimize her disability and live a rich and productive life.

An elective course assignment in the San Diego State University Rehabilitation Counseling masters degree program, Applications in Rehabilitation Technology, provided an opportunity to explore kayak adaptations for Michele. Michele attempted kayaking in the past with limited success, but hoped to find a workable solution to continue kayaking. Her primary barriers were her ability to maintain her balance while in the kayak and to stabilize the paddle position. A modified Roho™ seat cushion was designed with additional supports that provided added trunk stability. However, previous attempts at increasing her control of the paddle involved taping the paddle to her hands, creating an extremely unsafe situation should the kayak capsize. Initial discussions with Michele helped to identify her priorities in gaining control while paddling. Removing the pressure of supporting the weight of the paddle would enable Michele to focus her energy on moving the paddle along with the forward movement of the kayak.

Michele was given the Assistive Technology Device Predisposition Assessment-P, parts A, B and C (1). The results of this assessment indicated a very positive attitude towards assistive technology in general and with regard to kayaking, making her a good candidate for this project. The conclusion of the assessment determined that creating the assistive device would enable Michele to participate in kayaking. This would be a positive activity due to the importance of leisure activities in her life and her love of water sports. The proposed product, "Kayak Paddle Stabilizer (KPS)," would allow Michele to relax and concentrate on the motion of paddling, eliminating the fear of unsafe kayaking conditions.

OBJECTIVE

The objective of the KPS would enable persons with limited upper body usage to safely and effectively handle a paddle in kayaking. Michele required a paddle stabilizer for tandem kayaking, enabling her to focus her efforts in maneuvering the kayak through the added pivot feature of the KPS prototype. In addition to the KPS prototype, Michele utilizes the adaptive products as follows:

1) Two sponsons to stabilize the kayak (inflatable tubes which are attached to each side of the kayak to prevent capsizing).
2) A specially designed seat to provide a maximum range of pelvic and torso support.
3) Paddle gloves to help maintain grip on the paddle.

The KPS technology, although new, has the potential to enhance the quality of life for people with varying degrees of physical disabilities. Limitations of individuals with such physical disabilities are sometimes based on the lack of technology. As technology is developed based on the demand for such products, individuals with disabilities can help to remove barrier limitations that prevent them for accessing a better quality of life.

METHOD

The initial development of the KPS was first prototyped in the fall of 1998. It was determined that after the initial research there was a need and a market for products for people with varying degree of physical disabilities for recreational kayaking. Research was conducted primarily using the World Wide Web to investigate recent assistive technology development related to kayaking for individuals with disabilities. A variety of companies that advertised accessibility to kayaking for individuals with varying disabilities included the following: using heavy tape or rubber rings to secure their grip on the paddle, one-handed paddles, specialized gloves, inflated sponsons, adaptations with custom-made seat cushions, floatation devices, and assistance in transporting in and out of the kayak. To continue the project, additional technology and design help was needed. TRI ALL 3 SPORTS, a design and manufacturing company, was recruited to assist in technical support and prototype design.

Although the first prototype had its limitations, we recognized design changes necessary to fully implement the concept. The technical advisor from TRI ALL 3 SPORTS met with Michele and me to identify changes necessary to improve the KPS prototype. A series of photographs were taken to determine KPS prototype positioning on the different styles of kayaks. Based on the discussions of the positioning options, we determined that further design changes were needed for the second generation KPS.

Initial testing of the KPS prototype was conducted at the Mission Bay Aquatic Center (MBAC). The director and the assistant director were involved in the discussions concerning the concept and design. Their experiences with adaptive water sports provided us with an insight on design and functionality of the KPS prototype. Based on their experiences with adaptive water sports, they agreed that the KPS prototype would benefit individuals with varying physical disabilities. Although additional design changes are to be implemented to the KPS prototype, the concept is sound and KPS may be used on a variety kayak of styles.

During the evaluation at the MBAC, Michele's comments and responses were very positive, stating that the KPS prototype had great potential. Michele suggested that using gloves would improve her ability to grip the paddle. She also agreed that adding an adjustable height feature as part of the KPS prototype would keep her arms in the proper ergonomic position for paddling.

The concept of the KPS prototype design consists of a galvanized steel padded crossbar that is mounted with four legs with rubber suction cups on each side of the kayak cockpit. The KPS prototype can be moved forward and backward to accommodate the individual's height and reach. Mounted in the center of the horizontal crossbar is a vertical post that allows the paddle lock to pivot. The paddle is secured in the paddle lock by a bungee cord that is looped around the paddle.

The hooks on both ends of the bungee cord are hooked on opposite sides of the vertical posts on the horizontal crossbar. The paddle stabilizing post is the most critical part of the KPS prototype design. The stabilizing post holds the paddle in a secure position to the kayak while still allowing the individual to rotate the traditional figure eight paddling stroke. This design will allow the kayaker to rest his or her arms without losing the paddle. In the event of a capsize, the paddle will be attached to the KPS prototype. In addition to the suction cups attached to the kayak, a one inch heavy duty nylon webbed belt is attached to one leg of the KPS prototype to run under the kayak and secured on the other leg with a one inch nylon quick release buckle. The nylon line is pulled tightly to help secure the KPS prototype to the kayak. In addition, there is a safety line attached to the KPS prototype crossbar with one end attached to a footmes loop (metal bracket), which is attached to the deck of the kayak. In case of an emergency, the KPS prototype will stay attached to the kayak. The KPS prototype is adaptable to various kayak models, such as the ocean and sit-in kayaks. The KPS prototype is also portable and simple to use for kayak rentals.

The materials chosen for the KPS prototype are for design functionality and concept only. These materials totaled to $67.00, however it will not be used in the final production. The materials used in the final production will resist salt-water corrosion. The materials will also have a high degree of tensile strength, be lightweight and durable. They may be a combination of ferrous and non-ferrous material.

RESULTS

Through our research and development activities related to the KPS prototype, we have designed an effective adaptation for Michele to access tandem kayaking. Given our initial discussions with a number of individuals with disabilities, as well as with other water sports enthusiasts, the KPS could likely be adapted for people of all ages with a range of physical disabilities. If the development of the KPS prototype project allows the individual to live a fuller and richer life by participating in a sporting activity, then the objective of the KPS prototype was met.

DISCUSSION

The development of the KPS prototype has been a positive learning experience. All persons involved provided encouragement and an incentive to continue with the final product. Further development of the KPS prototype will include other individuals of varying disabilities to test and evaluate the performance of the product. Their suggestions and comments will assist us in the final version of the KPS design.

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ACKNOWLEDGEMENTS

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TECHNOLOGY FOR THE DEAF AND HARD OF HEARING

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ABSTRACT:
Hearing impairment separates hearing impaired people from information and social interaction. Children are being increasingly mainstreamed in classes for hearing children with the support of technological devices to bridge this access gap. This session reviews the range of devices used in schools and other support technology hearing impaired people use at home and in their professional lives, from amplification to a new handheld computer that delivers voice messages right to their pockets in text form.

BACKGROUND

Court decisions have increasingly promoted the integration of hearing impaired students into the mainstream with technological support. The presenter is a consultant for Carlsbad Unified School District, serving hearing impaired populations in 10 school districts. Job responsibilities include providing information on devices supporting children in those districts. Student populations include a range of abilities and handicaps, from gifted to autistic, deaf to multiply handicapped.

STATEMENT OF PROBLEM

Technology supporting the hearing impaired is increasingly entering the mainstream of education, yet there is a deficiency of information about these devices. The author offers resource information via materials to be presented at the RESNA 2000 conference 1) for attendees to review and discuss at the convention and 2) for attendees to take back to their respective service areas in the form of an informational booklet.

METHOD / APPROACH

1) 4 X 8 poster board displaying photographs and illustrations of the various forms of amplification and other assistive devices used by the hearing impaired.
2) 5 X 7 booklets for audience to take with them with lists, brief explanations of devices, and source information.
3) Discussion of the presenterÕs experience with devices presented.
3) Invitation to discuss specific situations and possible solutions to problems / example cases presented by participants.
Duration of session: One hour, 15 minutes

TECH FOR DEAF AND HH

Objectives

Attendees will:

1) View and discuss devices presented in this poster session.
2) Know how each device is used.
3) Acquire booklets listing devices discussed.
3) Utilize information included in booklets for the benefit of clients and other interested

RESULTS / DISCUSSION

RESNA members will have increased information and resources on assistive technology for hearing impairments. RESNA members will be able to ask questions of someone who has used some devices represented in the field and will be able to discuss / review their own experiences with these or similar devices.

REFERENCES / ACKNOWLEDGEMENTS (contact information is listed in booklet):

1. National Technical Institute for the Deaf, 52 Lomb Memorial Drive, Rochester, NY 14623-5604. Phone: 716-475-6824 (voice and TTY) **www.rit.edu** (Rochester Institute of Technology) OR **http://www.rit.edu/~418www/** (NTID).

2. Alexander Graham Bell Association for the Deaf, 3417 Volta Place, N.W., Washington, D.C. 20007-2778. Phone: 202-337-8767 (Voice/TTY). 202-337-8270 (fax). **www.agbell.org**

3. Wynd Communications. **www.wyndtell.com**

4. Krown Manufacturing, Inc, 3408 Indale Road, Fort Worth, TX, 76116. Phone: 817-738-2485 (voice), 817-738-1970 (fax), 817-738-8993 (TTY). **www.krowntty.com**, email: krowntty@aol.com.

5. California Relay Service: TTY: 1-800-735-2929, Voice: 1-800-735-2922.

6. Harris Communications, 15159 Technology Drive, Edan Pairie, MN 55344-2277. 1-800-825-6758 (voice), 1-800-825-9187 (TTY), 1-612-906-1099 (fax). **www.harriscomm.com**, email: mail@harris.com

7. Others as discovered.

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DEVELOPMENT OF A SEMI-AUTOMATIC BILL SORTING DEVICE

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ABSTRACT

The Semi-Automatic Bill sorting device was developed for people with visual impairment and cognitive deficits. This is an interactive device, which gives the user a place to put his bills, learn the concept of money transaction and carry out real time transactions. The user is guided step by step through the entire procedure to enable him to get bills of the correct denomination corresponding to the amount of money needed. The main purpose of the project was to teach and make the user independent.

BACKGROUND

The project was developed on the request from the teachers of the school and parents of the user, a student at the Eanes School, Austin. He is visually impaired and has limited fine motor skills. He has no concept of addition or subtraction of dollar values. The user previously used two safes to store his money. One was a simple box that was not portable and could not be carried around. The other one was an electronic safe that was not very interactive. Hence he was not able to make money transactions independently. He used to place the bills in his pockets i.e. five-dollar bill in right pocket and one-dollar bill in left pocket. This was really difficult to remember. The user was familiar with devices like talking calculator, computer, CD player. It was required to design and prototype a device that would be interactive, help the user to learn the concept of addition and subtraction of dollar values and also accommodate into the product domain with which the customer was familiar. Thus the objective of the project was to address the customer needs by designing and building a prototype of a Semi-Automatic Bill sorting device.

DESIGN METHODOLOGY

Customer Needs Analysis.

This was the first phase of the project. In order to satisfy the customer it was really important to know the needs of the customer his teachers and all others who were direct or indirect stakeholders for the product. The aim was to get to know "what" the customer wants. Interviews were conducted in order to know as to what the teachers and the parents and the user himself expected of the device. The customer needs were then rated according to the relative importance prioritized and translated into engineering requirements using the Quality Function Deployment methodology[1].

Concept Generation

This is the Genesis. It involves generating different concepts in order to meet the customer needs. The function structure for the device was realized and broken down into sub functions. Ideas were generated using the methods like brainstorming, 6-3-5 /C-Sketch method[1]. Many solutions popped up and the few, which met customer requirements and were also feasible in other respect, were selected for further consideration. Proofs of concepts were developed for different functionalities of the product, especially for the software program simulation, opening and locking mechanism of the compartments. Four concepts were short listed at this stage.

Concept selection
This was the most important step in development of the product since the decisions made at this stage affect the success or failure of the product. This was based on the results of Proof of concepts. It was learnt from the proof of concept that the 'sliding drawer type' made the device bulky. The four viable concepts generated during genesis were evaluated on the basis of how well they satisfied the customer requirements. The device needed to be interactive easy to use and manufacture. The concepts were evaluated using the Pugh's matrix[1], which favored the 'Pop-up type' bill sorting device, the name suggesting the opening motion of the compartments. This concept best met the customer requirements and also won over the others in cost and ease of manufacturability. Thus it was decided to design and build the Semi-Automatic Bill Sorting device.

DESIGN AND DEVELOPMENT
The next phase involved transforming the selected concept from paper to a working prototype. The decisions at this stage were driven by the customer needs. The basic customer need was to have a device that would be interactive and would help user to learn the concepts of addition and subtraction of dollar values. So it was decided to have a sound promotion and carry the user step by step through the entire process by means of instructions and feedback. It was important that the user be involved in the process to help him learn and develop. Hence the device was made semi-automatic. For the sound promotion a sound chip and micro-controller were incorporated. The micro-controller served to carry various logic operations[2]. An 8-ohm speaker was used to give auditory signals. A 9-volt battery was employed to run the device. A customized keypad was used to enter the amount of money needed. The layout of the keypad was made similar to what the user was accustomed.

The mechanical part was designed to have different compartments for different denominations of bills. There are four compartments, for $1, $5, $10 and $20. A slider serves as a combination lock to open the specific compartment. Lexan was used to manufacture the compartments. These were hinged by using plastic hinges in order to reduce the number of fasteners. The joints were made by using a chemical glue. It was tested successfully for giving a tough joint. It was required that the device gives feed back to the user at every stage. Thus it was necessary to incorporate sensors in the device. There are four contact sensors in each of the compartments which sense whether the compartments are empty or not. Then there are four sensors at the four positions of the slider corresponding to the four compartments, which would give feedback about the slider position. Finally, there is a contact sensor on the lock, which senses whether the device is left open, or not. These sensors were connected to the electronic module so that it would be possible to give auditory feed back to the user.

Logic and Operation of the device.

1. Suppose that the user needs 5 dollars. He would be required to enter 5 dollars. The device would check the status of its compartments.

Then it would give auditory feed back to the user to move the slider to the compartment containing five dollars. When the slider approaches the compartment the device gives feed back to the user and asks him to stop moving the slider and press the open key. This would open the specific compartment. After the dollar bill is withdrawn and if the device remains open then the user is prompted to close the device.
Now suppose there are no five dollar bills then the combination would be five 1$ bills.

2. The device also tells the user how much change he is supposed to get back.

3. If the device is empty then it tells the user to refill the device.

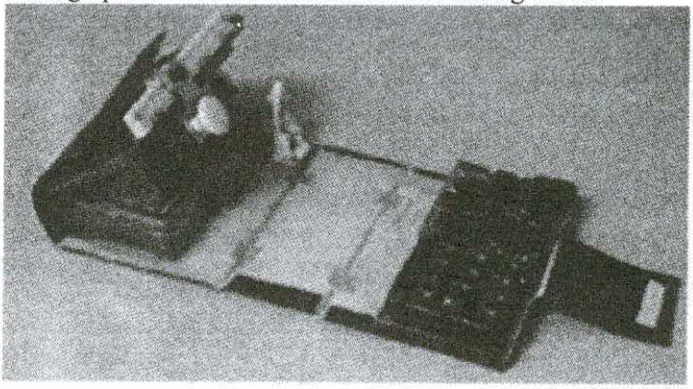
Evaluation

The final prototype of the Semi- Automatic Bill sorting device was overwhelming response from the customer his teachers and parents. It succeeded in meeting the design goals of being interactive and act as a learning aid for the customer. Most importantly, the user finds it comfortable to use. The teachers are thinking of putting it to a dual purpose

1. Use by the customer for real time transactions
2. Keep it in the school as a learning aid.

Thus the device has met its design goals and has had a great response from the user.

Photograph of the Semi-Automatic Bill Sorting device



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SHOPPING AID FOR THE VISUALLY IMPAIRED

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ABSTRACT

Health concerns often make it essential for people to read information on food packages. Our device makes shopping easier for the visually impaired by displaying a product's name, price, promotions, ingredients, and nutritional facts in a large, easy-to-read manner. The shopping aid consists of a barcode scanner and a laptop computer secured to a grocery cart. After the user scans a product's barcode, the laptop accesses a corresponding data file and displays the information. Large buttons allow the user to scroll through the information, jump directly to a heading, change magnification, reverse colors, and receive audio feedback. The device also keeps a running total of items selected. This device allows the visually impaired to shop independently and make informed product choices.

BACKGROUND & MOTIVATION

Millions of people in the United States are blind or visually impaired. Many of these people can read newspaper-headline-sized print or larger. However, the labels on most food items are too small for someone with a visual impairment to read. For many people, a product's ingredients, nutritional content, and price are the major influences in a purchasing decision. As a result, visually impaired individuals may be limited to purchasing only they items they already know about, or they may have to have someone else do their shopping for them. In addition, knowing the amounts of certain nutrients (e.g. sodium, cholesterol, etc.), or if a product contains certain ingredients, can be crucial for someone with a medical condition or special dietary needs. Therefore, this device provides potential health benefits as well as greater independence for individuals with visual impairments.

APPROACH

After developing the concept for the project, we contacted local supermarkets to find an interested partner. A Kroger store agreed to help evaluate the project, providing us with valuable feedback and an opportunity to demonstrate the device. We divided the project programming into two parts: the Data Entry Page and the Customer Interface. In addition, a mounting system was developed so the device could be securely attached to a shopping cart. At several stages in the design process, feedback was sought from ergonomists, engineers, and individuals with visual impairments. Therefore, the final design combines comprehensive input from a wide variety of sources.

DESIGN & DEVELOPMENT

In order to satisfy the objectives, the device must present the information in a format that is easy to read and retain while preserving the standard layout on food packages. Additionally, it must supply features to accommodate the preferences of each user such as variable magnification, color reversal, and audio feedback of the product name and price. Because the standard laptop keyboard can be intimidating to someone unfamiliar with computers and difficult to read for someone who is visually impaired, the device must use larger buttons whose functions can be easily identified. In designing the Shopping Aid for the Visually Impaired, there were two major areas to consider: programming and mounting.

Programming

Computer programming includes all of the code used to enter, access, and display the product information. The programming can be separated into the Data Entry Page (what the store employee entering the information uses) and the Customer Interface (what the visually impaired person accessing the information uses). Because both facets of the programming require a great deal of user interaction and graphical display, the Java programming language was chosen since it is well regarded in both areas.

Since the required product information is not found in any supermarket database, a user interface was created so that the supermarket can easily enter (or update) the product data. The Data Entry Page resembles a standard web page form with text fields for the various categories of information. When all of the information requested is filled in, the form is submitted and the data is written to a file unique to that specific product.

The second program used in the device is the Customer Interface, which supplies instructions for use, accesses the data files created by the Data Entry Page, displays the information, and accommodates user preferences. Upon running the program the "Welcome" screen appears and asks the user to scan an item or press a button to see instructions and button functions. When a product's barcode is scanned, the program uses that number to retrieve the data file and the "Product, Price, Promotion" screen will immediately be displayed. This page shows the product name, price and price per unit, and any promotional information the store wishes to provide. It can also be accessed by pressing the "P" button. From this page, the user has the option to scroll through the rest of the information or jump directly to the "Nutrition" screen ("N" button), "Ingredients" screen ("I" button), or the "Shopping Cart" screen (LIST button).

The "Nutrition" screen displays the Nutrition Facts table found on any typical food package label. The amount and percentage of each nutrient are presented. A list of up to 50 ingredients appears on the "Ingredients" screen.

The "Shopping Cart" screen shows a complete list of all items added to the cart and the individual price of each. The subtotal, tax, and total price also appear on this page. The current scanned item can be added to the shopping cart by pressing the "BUY" button. An abbreviated form of the product name is added to the shopping list and the price is added to the total. Similarly, the "REMOVE" button will remove the most recent item in the shopping list and subtract the appropriate price from the total.

Audio output is also provided for the product name and the price by pressing the "AUDIO" button (yellow speaker) when a product has been scanned. At any time, the user may change magnifications or reverse the colors. The magnification function cycles through fonts of 75, 100, and 120-point. The color reversal switches the foreground and background colors between black-on-white and white-on-black.

Mounting System

The mounting system provides a comfortable user-interface as well as a means of securing the laser scanner and the laptop to the cart to prevent theft and misuse. Because many of the potential users may not be experienced with computers, all of the functionality is supplied by using a small number of buttons. In addition, since the users are visually impaired meant that standard keyboard keys would likely be too small to accurately represent the identity of the key. To address these constraints, the mounting system consists of a cover, designed to replace the standard laptop keyboard with 11 large buttons, and a base plate, which is permanently mounted to the cart and serves as a platform for the laptop computer and the laser scanner.

The cover is constructed from 1/16-inch sheet metal. It has areas cut out to allow for the scanner plug and the buttons from a large button telephone. These buttons serve as mechanical links to selected buttons on the actual laptop keyboard (P = q, N = e, I = t, AUDIO = x, BUY = b, LIST = m, REMOVE = ., Magnification = i, Color Reverse = p, Scroll Up = \, and Scroll Down = (shift)). The cover is attached with a hinge to the front of the base plate so the cover can swing open when removing the laptop computer. On the back of the base plate, a rear mounting-bracket prevents the computer from sliding out of the back when the cover is locked in place. Two side brackets, mounted to the cover piece, provide the means to lock the laptop in place. Small pad-locks keep the cover down once the laptop is in place. Together, the brackets and the cover make the laptop computer totally immobile. The mounting plate for the barcode scanner stand is conveniently positioned at the back left corner of the base plate, nearest to the location of the scanner port on the left side of the computer. Towards the middle of the platform, there is a notched-hole cut out. This serves as the locking mechanism for the laser scanner. With everything locked in place, the mounting system provides a sturdy, secure, and convenient platform for the laptop computer and the barcode scanner.

INTENDED USE

The Shopping Aid for the Visually Impaired would be supplied to customers by participating supermarkets. Anyone wishing to use the device in a supermarket would simply request this at the customer service desk. Upon being given reasonable collateral (driver's license, credit card, etc.), the representative would attach and lock down the laptop computer and the barcode scanner using the mounting/security system. The customer could then shop at his/her leisure.

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THE SALIVA ASSESSMENT INSTRUMENT

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ABSTRACT

The Saliva Assessment Instrument (SAI) is an instrument used to evaluate, semi-quantitatively, the severity of the drooling problem in clients. It measures the amount, frequency and quality of the saliva overflow. To insure construct validity, test forms were mailed to 28 professionals representing 'experts' on drooling. Experts were asked if they agreed with the test items and to comment accordingly. Nineteen (n=19) forms were returned (68%), with an average agreement rate of 93% for each question by the majority of experts (85%), affirming construct validation. The data and comments were reviewed again to fine-tune the SAI.

BACKGROUND

In research and health care management, we seek to achieve outcomes that give credibility to our interventions (1). Measurement of the problem needs to be accurate, valid, and reliable. In the area of saliva overflow, many clinicians treat clients by trial and error until the correct management is found (2). Difficulty exists with measuring the problem in terms of quantity and quality of saliva, and frequency of overflow. Available evaluations do not account for these factors or do so subjectively. Adams et al. (3) used a semi-quantitative measure when investigating a double blind crossover study of two medications. A similar approach forms the basis of the SAI.

HYPOTHESIS

Experts in saliva overflow agree with test items included in the SAI.

DESIGN OF INSTRUMENT

This six-part instrument examines many aspects of saliva overflow. Part I covers demographics and the client and caregiver's perception of the drooling problem. Part II gives graphic representations for optimal positioning of the client. This allows examiners to maintain a consistency with clients before test observations begin. A semi-quantitative illustration of the amount of saliva overflow is provided to the clinician in Part III. It allows both the caregiver and clinician to determine which line drawing best matches the amount of saliva overflow produced by the client. Part IV is comprised of the oral structure and function of the client's mouth including mobility of the tongue and lips and the dentition of the client. Part V addresses problem solving skills and gives some information about cognition. Part VI is a frequency of saliva overflow diary. It is meant for assessment over a longer period of time (week) and is given to the caregiver to take home. Quality of saliva is addressed in this section also.

CONSTRUCT VALIDITY

Definition

Because standardized instruments measuring saliva overflow do not exist, there is very little empirical data available to support the validity of this instrument. As of yet, the SAI has been used in a pilot form only. Construct validity is based on theory that in turn should be supported by empirical knowledge. Construct validity assures theory and empirical knowledge are one (4). Because so little empirical data exists about measuring saliva, others in the field of saliva overflow were called upon to give their consent to the soundness of this instrument. With additional clinical use, other parameters of validity and reliability can be determined. The agreement (mean=93%) by experts (85%) in numerous health care fields substantiates the instrument's construct validity.

Subjects

In 1990, 28 professionals gathered at the Kluge Children's Rehabilitation Center for the Consortium on Drooling (5). These 28 professionals from North America represented: speech/language pathology, developmental pediatrics, otolaryngology, pediatric dentistry, plastic surgery, nursing, psychology, occupational and physical therapy, rehabilitation engineering, special education, aerospace engineering (NASA), research design, and parents. Participant selection was based on extensive clinical and/or research experience with the problem of saliva overflow. These people spent one and one-half days discussing a better way of assessing, treating, and managing problems with saliva overflow in children. These same experts were contacted again in early 1999 to obtain their feedback about the Saliva Assessment Instrument.

Twenty-eight assessment forms were mailed to professionals with expertise in the field of saliva overflow. Nineteen forms (68%) were returned (n=19). They were asked to agree or disagree and give comments for each of forty-five items on the SAI.

RESULTS

Respondents agreed with the items presented with a range from 79%-100% (mean=93%). The majority of the questions (93%) were agreed upon by 85% of the professionals. See Table 1 for disagreements. Table 2 illustrates 100% agreement of test items.

Table 1: Items Not Meeting Goal of >15% Disagreement by Panel Experts*

Items	*% Disagreed*
#4 – Associated problems	21
#5 – Client's perception of drooling	18
#28 – Teeth illustrations	21

Table 2: Items Agreed Upon by 100% of Panel Experts*

Items	*% Agreed*
#6 – Caregiver's perception of cause of drooling	100
#17 – Desired client position	100
#19-23 – Oral structure and function of the lips	100
#25 – Test for occlusion	100
#34-36, 38,41 – Oral structure and function of the tongue	100
#43 – Does the client use adaptive switches to activate toys, computers, etc.?	100

*Not every respondent stated agreement or disagreement with each item. Some items were left blank.

Each respondent who commented on the individual items had his/her comment evaluated during a second review. These reviewers had experience with saliva overflow and made a judgement as to the significance of the comment in the refining of the SAI.

DISCUSSION

Determining the efficacy of interventions in the field of saliva overflow will depend on careful measurement of the problem. The SAI represents a single step towards measurement of saliva overflow. The semi-quantitative nature of the amount of saliva overflow as depicted in the SAI offers the clinician a level of objectivity in assessing this problem that does not exist in other instruments. When reviewing saliva overflow instruments, few exist as dedicated instruments (2) but rather are part of other feeding and swallowing tests. The SAI is distinct from others by not only addressing saliva overflow, but also by the agreement of 'experts' in the field on its construction. The agreement on including these test items (93%) by the majority of these experts (85%) attests to the soundness of the instrument. Future work on reliability and validity will need to be addressed as the instrument is used clinically.

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MAKING THE MOVE TO INDEPENDENT LIVING: A CASE STUDY

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ABSTRACT

Young people with severe physical disabilities who want to make a move to independent living need the support of assistive technology to help them with many aspects of their lives. When a range of products is introduced to a person, the provision and implementation of services has to be well co-ordinated. When this approach is not followed, the results will be users being provided with devices that are not compatible with each other. This paper describes an integrated system that a young man with spinal muscular atrophy uses to control his wheelchair, computer and electronic aids to daily living. The concerted efforts by three teams responsible for different technical devices are highlighted.

BACKGROUND

Cam is a 19 year old male with a diagnosis of Spinal Muscular Atrophy. He has a severe rotokyphoscoliosis, severe muscle weakness and is dependent on a mechanical ventilator for breathing. His functional movements are limited to finger movements with his wrist supported on a flat surface. Cam is totally physically dependent on others but is very able to direct his own care. He attends a regular secondary school program and has a career goal of computer programming. Cam is actively involved in electric wheelchair hockey and is enthusiastic about computer game.

At the age of 19, Cam is ready to make a transition from residential care facility to independent living in an attendant care environment. To support this transition, a cross program multidisciplinary team assessment was initiated. Team members came from three different programs at Bloorview MacMillan Centre. The team consisted of occupational therapists, a speech-language pathologist, an electronics engineer and a technician.

OBJECTIVE

To be able to live independently in an attendant care environment and to pursue his career goal, Cam needed the support of assistive technology in the areas of mobility, personal care, communication, academic and prevocational activities, and entertainment. With the many different devices that he needed to control and with a limited number of control sites, an integrated system was necessary for Cam to access all the devices. Cam's primary concern was to have a system that is responsive, accurate, and reliable, with a simple interface that is easy for his caretakers to understand and use. The aesthetics of the system is also an important consideration for Cam.

DESIGN AND IMPLEMENTATION

Recognizing the need for co-ordination of services and integration of all of the technical devices, all team members were involved at the onset and worked closely together throughout the implementation process. At the beginning, joint assessments were carried out to make sure that Cam's needs were met and that the various devices would not interfere with each other and would blend together to offer the best solution. During the installation process, the teams consulted each other frequently and took part in trouble-shooting together.

The teams agreed that proper seating facilitates access to adaptive devices and should be the first step in the technology intervention with Cam. Due to Cam's musculoskeletal deformities and muscle weaknesses, his seating system had to provide intimate postural support, maximize function and be safe, compact and comfortable. The use of modular components from a minimum number of vendors was important to simplify service issues and to increase compatibility of components. A Contour U back with a padded chest belt provided intimate trunk support and its aluminum pan provided a surface for mounting various control modules. Custom configuration of a Whitmyer SOFT headrest gave occipital head support that was adjustable as well as providing a chin support that was mounted to the headrest instead of the tray. This increased the ease and safety of transfers and eliminated interference with arm placement on the tray. Custom arm and wrist blocks were added to ensure forearm and hand placement regardless of tilt angle.

Cam wanted a chair that would not breakdown and that had high speed capability for wheelchair hockey. To meet this goal, options in power chairs and controls were considered. Cam had perfected his use of capacitative touchplates to drive his power chair for many years. This was the most desirable control method. Placement of the touchplates was configured to leave the center of his tray clear for books. A transparent tray was used to allow Cam to see the floor in front of his chair. For power mobility, Cam preferred the Invacare brand of chairs due to their seamless electronics. The Storm frame offered direct drive and a cleaner undercarriage, hopefully decreasing the incidence of breakdowns. A Tarsys tilt was integrated into the Invacare Storm power chair, with a custom ventilator mount to secure the ventilator and associated equipment. The external battery for the ventilator was placed behind Cam's feet on the frame.

Text entry speed, fatigue and hardware and software compatibility were the primary considerations in selecting a computer access method. Kurzweil Voice Plus was chosen as it was the only speech recognition software that could accommodate to Cam's limited breath control and fluctuating voice volume. It could filter out the sound of the ventilator and involuntary breath sounds. Single-switch Morse code input using Bloorview Mini-Morse was set up to be interchangeable with speech input because Cam has limited tolerance for each input method. A responsive mouse control was a priority for Cam when navigating Windows and playing games. This was achieved with Drive Point. Six switches were used to provide eight directional controls and a two-buttons mouse. As Cam is not able to handle books independently, a scanner was added to the computer system so that with assistance he can scan in reading material. He also has support for access to reference material on CDs and through the Internet.

For Cam to be independent and safe in his apartment, he would need to control telephone, apartment doors, home entertainment equipment and X-10 appliances. The SICARE Pilot, a voice activated EADL system was selected because it allowed direct control to a chosen function. It has a small visual output display, is reliable and was aesthetically acceptable. The SICARE Pilot can be altered to use switch activation on those occasions when Cam's voice quality is diminished. This unit is portable allowing Cam to control the equipment from bed. A Tykris phone was provided so that Cam had access to a telephone in the event that the SICARE pilot would not respond. Additional considerations for the telephone include the capability of the telephone to hold one hundred numbers, and support for Cam to independently add/delete the numbers.

Having considered control functions for seating and mobility, computer access, electronic aids to daily living and entertainment equipment separately, the control systems had to be integrated onto the wheelchair. A combination of six touch-sensitive switches and four microswitches on his tray were used to access his equipment. Mounting of all of the devices so that they were functional and aesthetically acceptable was a challenge for the team. The wheelchair batteries were able to provide power to all the chair-mounted devices, eliminating the need for separate power sources. In addition to the devices described above, future implementation of the Bloorview CellLink cellular phone needed to be considered in the implementation plan. The design of the integrated system is illustrated in Fig. 1. With the many connectors around the wheelchair, Cam was most concerned about making the connection procedures simple for his caretakers. Wherever possible, he preferred to be able to see the connectors so that he could direct his caretakers. Safety is always a concern in provision of a complex technical system. A direct switch link was made for telephone access so that emergency calls could be made in the event that the wheelchair breaks down.

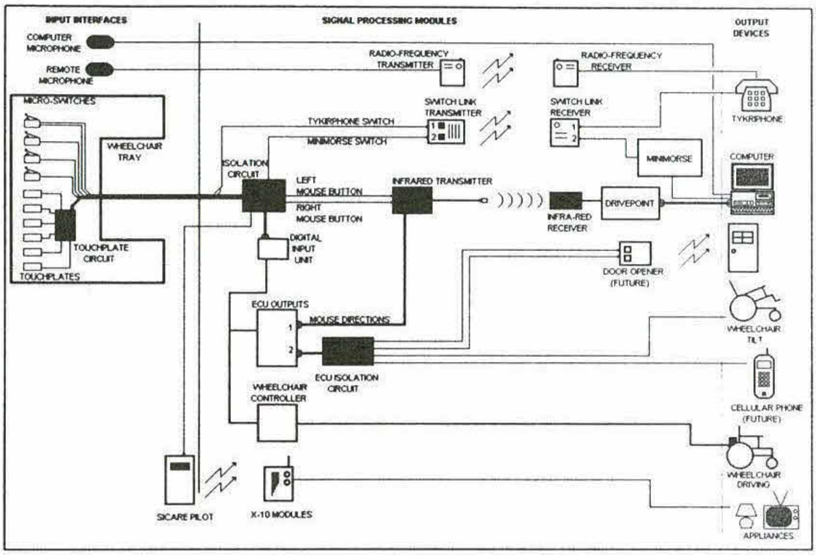

Figure 1: Design of Cam's System

The implementation process was not without challenges. While partial funding for seating, mobility and computer access are covered by the Ontario government, electronic aids to daily living and entertainment equipment are not covered. Securing third party funding was a lengthy process. The integrated nature of all devices on the wheelchair required Cam's presence at our Centre for many appointments. Transportation and attendant care for the visits was difficult to arrange, and this caused delay in implementation. Once all the devices were installed in Cam's room, the interference between his devices and those of his roommate necessitated changes in design and negotiation between the two young men to schedule time for using the devices. The noise level in a room housing two young men with TV and stereo equipment interfered with the use of speech recognition devices. As a compromise, the implementation of speech recognition device will be delayed until Cam moves into his own apartment and has control of the background noise level. The fast pace of changes in the technical field necessitated changes in the design to accommodate new devices as some equipment originally recommended by the team was discontinued by the time funding was available.

DISCUSSION

Assistive technology enables young people with physical disabilities to live independently, to pursue their career goals and to enjoy a fuller life. It is essential for providers of technology to be aware of the importance of a co-ordinated approach to service provision. Involvement of all team members from the onset ensures an efficient effort to blend components and offer the best solution for clients.

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THE TRAVEL MASTER: A SIMPLE DEVICE DESIGNED TO ASSIST PEOPLE WITH VEERING PROBLEMS

JP/WSU

ABSTRACT

For years, mobility specialists and other service providers have struggled to find ways to assist those with veering problems to achieve the milestone of independent travel. While high-tech devices like the laser cane and the Sound Source are helpful in this regard, they are often expensive, impractical, and complicated. To solve such problems, the author, a visually impaired college student who works as an adaptive technology specialist at the Technology Resource Center of Dayton, Ohio, unveils the Travel Master, an easily-made device that helps people learn to avoid behaviors that increase the likelihood of veering.

BACKGROUND

In recent years, the issue of veering has gained prominence among mobility specialists. At issue is how to curtail such behavior, and while it may seem simple researchers have been struggling for years to arrive at a practical solution to the persistent problem of veering among individuals with vision and motor impairments. In many cases, excessive veering can greatly hinder, or even completely prevent, such individuals from safely traveling alone, which significantly diminishes their quality of life in such core facets as independent living, recreation, and competitive employment, and While extensive research has been undertaken in these three areas, it is grossly lacking in the area of independent travel and veering difficulties. As a result, most of my knowledge in this area, which has enabled me to come up with the Travel Master design, was acquired through personal communications with numerous mobility specialists and rehabilitation service providers.

PROBLEM

As iterated in the previous sections, the primary concern is how to reduce the frequency of veering among pedestrians with vision and walking difficulties. While devices like the Sound Source can help teach someone the concept of a straight line under simulated travel conditions, such a device is not useful during actual travel since it cannot be taken along and utilized on walks and other ventures. What is needed on such occasions is a portable and inexpensive contraption that can be tailored to make a person aware of his or her behaviors that increase the probability of veering, and the Travel Master accomplishes this feet in addition to being inconspicuous.

RATIONALE

The need for a device to reduce the frequency of veering among travelers with certain types of impairments is justified because independent travel is paramount if one is to enjoy a well-rounded and decent quality of life in core areas like recreation and employment. According to Dave Stegoner (personal communication, November 18, 1999), an orientation and mobility specialist in Dayton, Ohio, current attempts at developing a device that indicates to people when they have veered, which way they have veered, and how far they veered off course have largely failed either because of the enormous expense of developing and/or marketing such a device or due to practicality constraints (it is difficult to carry around a large contraption). As Craig Allen (personal communication, October 27, 1999), a mobility specialist in Troy, Ohio, points out, certain behaviors, e.g., head turns to one side and lack of hand centering while using a cane, significantly increase the probability of veering, and therefore I think a device that helps people avoid and correct these behaviors will increase the travel potential of many individuals with such difficulties.

THE TRAVEL MASTER

PRODUCT DESIGN

The Travel Master is actually a very simple design that costs approximately $75 to make and implement. In its design, three distinct materials and devices are needed, sun glasses, an elastic headband, and two strips of stretchy rubber approximately 14 inches in length. The device can be constructed in three steps. First, secure the sun glasses around the head with the headband or specialized holding strap. This insures that the glasses do not fall down or slide. Secondly, tie one end of each strip of rubber to each earpiece of the glasses, leaving two loose ends one hanging from each side. Finally, bring the loose ends under their corresponding arm and tie the two together around the lower part of the neck. When complete, the strips of rubber should resemble the shoulder straps of a backpack. From this design, a person is made aware when he/she has a drastic head turn to one side or the other--when the head is turned far left, for instance, the right shoulder receives a gentle tug from the rubber, but when the head is fairly straight there is a neutral pull on both shoulders (in other words, there is a balance effect). In this way, the traveler with a severe head turn can learn to correct the problem and prevent many veering episodes.

DEVELOPMENT

I came up with the idea for this product after working with a client. Since I am an intern at the Technology Resource Center, I am asked to work with people with a variety of disabilities, and many have vision and veering difficulties. Because the client I was working with had a tendency to turn his head drastically to the right, I decided to try to design something to teach him not to engage in this behavior. What he needed was a relatively inconspicuous, inexpensive contraption that he could use on a daily basis, or at least until he got into the habit of walking with his head straight. After trying many designs, I decided upon the one mentioned above since it seemed to have the greatest potential to benefit multiple individuals. In addition, it was almost unnoticeable and thus did not evoke societal stigma associated with many adaptive devices. As Lazzaro (1993) (1), explicitly implies, it is vital to consider such factors in addition to cost and the client's preferences when modifying or developing a device since these factors largely dictate the perceptions and attitudes of employers, friends, and relatives.

EVALUATION

Overall, the Travel Master is an effective design given its cost, function, and portability. I really like the fact that it is relatively unnoticeable, which as Falvo (1991) (2) points out has positive psychosocial implications for the user. From its success with two different individuals with veering problems resulting from drastic head turns, I think it has great potential. Nevertheless, I have noticed two small flaws in its design. First, it can become uncomfortable after some time. While personally wearing this device for a few hours, it began to feel tight, and the rubber felt sticky on my neck and shoulders when I began to sweat. I have received similar complaints from the two individuals I designed the device for. Secondly, I have found that it is difficult to put on and take off. Because of the design, one must tuck the straps under the shoulders and tie them off around the lower part of the neck, which some people cannot do independently, and it is for these same reasons that some individuals have difficulty in independently removing the device. Undoubtedly, I will need to work to enhance this design and work out these and other bugs, but overall I am very pleased with its results thus far.

DISCUSSION

From my experiences, I have found the Travel Master to be a successful deterrent to head turning. However, as previously mentioned, a drastic head turn is not the only behavior that leads to increased veering. The other such behavior is improper use of the cane, more specifically a lack of hand centering. Craig Allen (personal communication, October 27, 1999) and Dave Stegoner (personal communication, November 18, 1999) hold that the touch technique for cane travel contains in excess of 25 different integral parts, one of which is hand centering (the elbow should rest snug against the ribcage with the hand centered towards the bellybutton). Hand centering is a problem for many cane users in addition to head turning. Because of this, I have my sights set on incorporating this behavior into the Travel Master design in order to further decrease the frequency of veering.

ACKNOWLEDGEMENTS

While I came up with the specifications for the Travel Master by myself, I owe thanks to several people for their time and helpful information, including Dave Stegoner, Craig Allen, and James Hawkins. Being mobility specialists, Mr. Allen and Mr. Stegoner were able to provide me with valuable information regarding veering problems. For his part, Mr. Allen cued me into several behaviors that lead to veering such as head turns to one side or the other and improper use of the cane. Mr. Stegoner, on the other hand, cued me into the shortcomings of previous attempts to prevent veering, which kept me from making similar mistakes. Finally, I owe a great deal of thanks to James Hawkins, a fellow student who allowed me to try out my design on him.

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Augmentative and Alternative Communication (Topic 2)

AAC COMMUNICATION RATE MEASUREMENT: TOOLS AND METHODS FOR CLINICAL USE

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ABSTRACT

Augmentative and alternative communication (AAC) rate enhancement is a significant goal for all working in this area of assistive technology. Automated language activity monitoring (LAM) performance tools allow the calculation of communication rate based on logged data from the use of actual AAC systems by people who rely on them. A standard method for calculating peak and average communication rate in the clinical setting is proposed. Implications are significant in the areas of clinical intervention, outcomes measurement, and research.

BACKGROUND

The goal of AAC intervention is the most effective communication possible for the individual. Generally, effective communication is accomplished through spontaneous novel utterance generation (SNUG). Measuring AAC communication rate can provide valuable information on the efficacy of various rate-enhancement strategies to improve interactive communication. However, we make decisions about the benefits of available strategies without much assistance from a research base (1). The content of this paper focuses on communication using assistive technology.

For people who rely on AAC, communication rate almost always is far slower than normal speech. Yet communication effectiveness can be a significant factor in determining personal achievement in life. Therefore, every effort must be made to maximize communication rate for this population.

The recent development of automated logfiles (2) and the AAC language activity monitor (LAM) (3) for clinical use has made available quantitative data on which to base intervention decisions. The LAM has made possible various analyses of data that can prove useful to clinicians as well as to people who rely on AAC. Analysis of AAC language samples collected using LAM has provided information similar to that available from samples of speaking individuals. This includes measures of vocabulary diversity and linguistic complexity. In addition, LAM data, because it includes language event time stamps, has allowed identification of language representation method usage.

OBJECTIVE

The development of LAM makes practical for the first time the quantitative measurement of communication rate as part of the clinical intervention process. However, there has been no standardized definition of or method of calculating communication rate for people who rely on AAC. Further, no tools have been available to automate the measurement of communication rate. The objective of this work has been to develop a standardized method of rate measurement.

METHOD

This paper proposes a method of calculating communication rate. Communication rate generally is reported in terms of words per minute. This proposal is based on those units. Language samples from LAM are reported in the following model:

20:37:00 "I need "
20:37:05 "*[VOLUME UP]*"
20:37:06 "*[VOLUME UP]*"
20:37:07 "*[VOLUME UP]*"
20:37:14 "something "
20:37:16 "to drink "
20:37:19 "i"
20:37:20 "m"
20:37:24 "m"
20:37:28 "ediately "

The time stamp is a 24 hour format with one second resolution. Items included inside the *[-]* are non-language events. The first process applied to raw LAM data is often the editing of the data into utterances, e.g. "I need something to drink immediately ". This prepares the data for analyses using commercially available or custom computer-based language transcript analysis tools.

The proposal presented here is that communication rate measurement be based on SNUG utterances and that the language sample include at least ten such utterances. While the use of preprogrammed messages by people who rely on AAC is not uncommon, the inclusion of these items in a rate measurement calculation would be misleading. This is based in part on analysis of LAM pilot study logged data that shows use of preprogrammed utterances to be under 1% of total AAC system communication from high-end users on technology that supports all language representation methods (4).

Both peak and average rates may be of interest. Peak is being defined as the highest rate for a particular utterance in which the number of words following the first event exceeds the corresponding mean length of utterance (MLU) for the entire sample. Average rate is calculated on the basis of all utterances included in the language sample and is weighted according to the number of words in the utterance. Here is a listing of steps to be taken to convert raw LAM data into peak and average words per minute.

1. Edit LAM sample into utterances.
2. Remove non-language data and adjust the time stamps accordingly.
3. Remove preprogrammed utterances.
4. Calculate words per minute for each utterance.
   A. Start time (S) = time of first event in the utterance (one second resolution).
   B. End time (E) = time of last event in the utterance (one second resolution).
   C. Words (W) = words after first event in the utterance.
   D. Words per minute (WPM) = (W / (E – S)) X 60.
5. Words per minute peak (WPMP) = Highest WPM of an utterance longer than the sample MLU.
6. Words per minute average (WPMA) = Average WPM, weighted by number of words.

For the example above (I want something to drink immediately), the first event (I need) occurred on the minute (00). This is the start time (S). Seven seconds were used to adjust the volume. Thus "something " occurred an adjusted seven seconds (14 – 7) into the utterance. The utterance concludes with "ediately " at an adjusted 21 seconds (28 – 7) into the utterance. So the end time (E) is 21 seconds. The utterance contains six words, but two of them were the first event. This leaves the word count (W) at four. Rate for this utterance is then calculated:

WPM = (4 / (21 – 0)) X 60 = 11.4 words per minute.

This utterance has four words following the first event. If the sample MLU (following the first event) is under 4.0, this utterance would be included in the identification of peak rate. For the average rate calculation each utterance is weighted according to the number of words (following the first event) in the utterance. This results in a more representative measure of overall communication performance than the true average.

DISCUSSION

The availability of standardized methods for measuring and calculating communication rate has implications in the areas of clinical intervention, outcomes measurement, and research. The end result of the use of these tools is the enhanced communication and higher personal achievement of people who rely on AAC.

By having measurement tools and methods, additional information on the acquisition of personal AAC performance will be forthcoming. Of great value will be an improved understanding of the distinction between systems that are easy to use at first encounter and those that provide the most effective communication in the long run. Understanding the characteristics of the learning process should impact AAC assessment approaches.

Through the use of standardized methods based on quantitative logged data, the field of AAC is making the transition from an art to a science.

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AAC SELECTION RATE MEASUREMENT: TOOLS AND METHODS FOR CLINICAL USE

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ABSTRACT

Augmentative and alternative communication (AAC) rate enhancement is a significant goal for all working in this area of assistive technology. The speed of making selections from an array of choices is one of the factors that influence communication rate. Automated language activity monitoring (LAM) (1) tools allow the measurement of selection rate based on logged data generated by actual AAC system operators. A method for measuring selection rate is proposed. Implications are significant to the clinical assessment and intervention processes.

BACKGROUND

The AAC clinical processes initiate with a team commitment to work toward the goal of AAC. The team agrees to provide the supports and services that result in the most effective communication possible for the individual. Generally, effective communication is accomplished through spontaneous novel utterance generation (SNUG). For people who rely on AAC, one measure of communication effectiveness is communication rate, which is almost always far slower than natural speech. Therefore, every effort must be made to maximize communication rate for this population. Communication rate is influenced by many factors. By far the most significant factor can be the language representation method (LRM) employed for accessing core vocabulary. However, the speed of making selections also can be an important factor.

Once the team has determined the LRM(s), decisions regarding the most appropriate selection technique must be made. Research on how different AAC configurations affect speed and efficiency is needed to facilitate the clinical decision-making process for motor access (2). For most teams, determination of selection techniques has been qualitative ratings of speed and reliability. The measurement of selection rate has been based on clinical intuition, trial-and-error counts, or not documented.

The recent investigation into automated data logfiles (3) and the development of AAC language activity monitoring (LAM) for clinical use has made available quantitative data on which to base assessment and intervention decisions. The LAM data can be used to produce quantitative measures of various aspects of AAC system use, including both language and non-language parameters.

OBJECTIVE

The objective of this work is to provide a method of using LAM tools to measure the selection rate in an AAC system. This information allows the comparison of different techniques, the areas of a keyboard, for example, that are best accessed, the measurement of progress in learning to use a particular technique, and changes in rate that might occur as a result of other short term (e.g., fatigue) or long term (e.g., learning curve, physical improvement or deterioration) factors.

METHOD

The human interface information transfer rate has historically been measured in terms of bits per second. (The rate for able-bodied people is generally considered to be under 100 bits per second. (4)). Consistent with historical measures, for this work the selection rate also is being reported in terms of bits per second.

The size of the array (A) (e.g., number of keys on a keyboard) from which choices are being made determines the number of bits (N) that are available with each choice. $A = 2^N$. $N = \ln(A) / \ln(2)$. The number of bits (N) for various array sizes (A) is presented in this chart:

A	N
128	7
64	6
32	5
16	4
8	3

Thus, if a person were able to make one choice per second from a keyboard with 128 keys, the selection rate would be seven bits per second. It is important to make the distinction here that the selection rate does not constitute the AAC communication rate. While the selection rate influences the communication rate, other factors, such as the language representation methods employed, do as well.

Language samples from LAM are reported in the following format: **20:37:00 "content"**. The time stamp wis a 24 hour format with one second resolution. A space and two quotation marks follow the time stamp. The content of the language event being recorded is between the quotation marks. Each event is presented on a new line.

A selection rate measurement would consist of having an AAC operator enter a list of selections. The LAM would time stamp and record these selections. It is essential that the AAC system be configured such that each selection generates a language event, one or more characters. Most AAC systems can be programmed to provide for this.

Issues related to selection rate measurement include the number of choices selected in the test, the particular choices to be included, the order of their selection, and the size of the sample required to produce useful results. Standardizing on these items would allow the information to be most useful. Thus, the following proposal is offered.

The number of choices included in the test should be 10% of those allowed by the system, with a minimum of two. Thus, if the system selection array is based on 128 keys (8 x 16 matrix), 13 keys would be included in the test. If a pointing technique is being used, the keys would be those forming an "X" in the center of the selection area. For a row-column scanning system the test keys would be the diagonal keys starting in the upper left corner of the array. Keys are selected in an order that avoids or minimizes adjacent keys being selected in sequence when using a pointing technique. The duration of the test is at least thirty seconds but long enough for all test keys to be selected the same number of times.

The examiner starts the test with a selection that produces a start indicator in the LAM record. The LAM record then shows the start time (S) and end time (E) in seconds for the test. The selection rate (SR) in bits per second is defined as follows, where C is the number of choices made from an array of A keys: $SR = (C \times \ln(A) / \ln(2)) / (E - S)$. For example, if the LAM data showed that 26 selections were made (from an array (A) of 128 keys), the start time was 09:37:17 and the end time was 09:37:58, then the selection rate would be 4.4 bits per second.

DISCUSSION

AAC professionals, in order to increase the selection rate, generally will want to maximize the number of keys available to the user. However, it is clear that range of motion and pointing skill put limits on what can be done in this area. Fitts' Law (5) offers some theoretical predictions on how quickly an individual can make choices of targets of a given size located a given distance from a starting point. Since the application of Fitts' Law in the clinical setting would require information not generally available, the more practical approach is actual trials on keyboards of different sizes.

Selection skills often require training time for development. With quantitative measurement of performance, rational decisions can be made relative to level and stability of performance.

Consideration of error correction is not provided in the above procedure. This is because the number of selections necessary to correct an error is a function of features of the AAC system. The time used in generating errors is included in the test, but no consideration of correction time.

The AAC clinician is cautioned that other factors can influence communication rate. Some of these factors can be far more significant than the typical differences between some selection techniques. For example, motor planning can be important in developing communication speed. Also, an alphabet-based language representation method may produce only a single letter per selection while a whole word per selection may be produced by other methods. And navigating from screen to screen to access single meaning pictures can be problematic and time consuming.

The availability of methods for measuring selection rate has implications in the areas of clinical intervention, outcomes measurement, and research. The end result of the use of these tools is the enhanced communication and higher personal achievement of people who rely on AAC.

By having measurement tools and methods, additional information on the acquisition of personal AAC performance will be forthcoming. Understanding the characteristics of the learning process should impact AAC assessment approaches.

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EFFECT OF SYSTEM CONFIGURATION ON USER PERFORMANCE WITH WORD PREDICTION: RESULTS FOR USERS WITH DISABILITIES

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ABSTRACT

Six subjects with physical disabilities transcribed text using two different configurations of a word prediction system. System configuration had a meaningful effect on text entry rate for half of the subjects, with an average of over 60% difference between configurations. For the other half of the subject group, the effect of configuration was less clear, perhaps confounded with the effects of individual variation and increase in skill level over time. Results support the possible benefit of an adaptive system that configures itself to the needs of a given user.

BACKGROUND

The purpose of this experiment is to examine the effect of system configuration on user performance with word prediction. Word prediction systems can be configured to more closely meet the needs of a given user through the settings of numerous parameters. The system configuration may affect the user's performance with the system, although the effect may not be easily intuited. Various studies have reported on user performance with word prediction (e.g., [1]), but we have found none that has systematically studied the effect of system configuration.

There are two reasons for our interest in how system configuration influences user performance. First, it has direct clinical relevance. Clinicians might be able to configure a system to provide better performance for users if they had a greater understanding of the likely effects of specific settings. Second, it is part of a larger project to develop a word prediction system which will automatically modify, or suggest modifications to, the system configuration in order to maximize the user's text entry rate. A key component in developing these experts is a good understanding of the system parameters that make the most difference to user performance.

RESEARCH QUESTION

How does the configuration of a word prediction system affect the text entry performance of an individual user?

METHODS

Subjects. Six individuals participated, each with a physical disability with respect to keyboard use. Medical diagnoses included two people with multiple sclerosis, two with cerebral palsy, and two with spinal cord injuries. All were able to use a keyboard with one or more fingers or a mouthstick. All were highly literate, with at least some college education. Only one was an experienced word prediction user; the others were novices with respect to word prediction.

Experimental Design. The study employed an ABA single case design, spaced over two sessions. The general goal was to establish two different word prediction system configurations (A and B) for each subject, then measure and compare performance for each configuration. In the first session, baseline performance with word prediction under Configuration A was measured. In the second session, performance with word prediction under Configuration B was measured, followed by a second measurement of performance under Configuration A. Each phase of the ABA design consisted of a minimum of three trials. Each trial involved transcription of two sentences, with the same sentences used throughout the experiment.

System. A testbed word prediction system was developed for the purposes of this study. This provided a completely flexible method of configuration, a 40,000 word dictionary, and fully integrated data collection facilities. (One person used her own word prediction system, Co:writer, since it was tailored to accommodate her vision problems.)

Definition of System Configurations A and B. The configuration of the word prediction system was defined as the choice of values for the following parameters: when the prediction list is first presented, when the list is removed following first presentation, the number of words in the list, and the minimum number of letters in words in the list. All other system parameters and the word prediction dictionary itself remained constant across all conditions.

The baseline condition, Configuration A, was the same for all six subjects. The prediction list was always displayed, there were 6 words in the list, and there was no minimum length for words included in the list. Configuration B represented an attempt to influence performance by adjusting the configuration parameters based on results of the first A phase. Observations of subject performance during the first A phase were complemented by use of a model equation to predict a configuration that would result in at least a 20% change relative to baseline performance [2]. As an example, one subject's Configuration B used a 3-word prediction list, which appeared on the screen only after the first 2 letters of a word had been entered and contained only words of 5 letters or more.

Data Analysis. The primary measure was text entry rate for each trial, measured in characters per minute. Differences in text entry rate between the A and B phases were assessed graphically for each subject. A visually obvious change in level from the first A phase to the B phase, followed by at least a partial reversal in level with the second A phase, was taken as evidence of a meaningful difference. Additionally, the following quantitative criterion was established for a meaningful difference. For each subject, average text entry rate for each phase was computed using the last two trials in the phase. A percentage difference of greater than 20% for the B phase relative to both the baseline and reversal A phases was taken to be a meaningful difference.

RESULTS

As shown in Table 1, half of the subjects (ML, KM, MK) showed meaningful differences in text entry rate when using different system configurations. For these 3 subjects, text generation rate averaged 61% faster with Configuration B relative to the first phase with Configuration A. The left half of Figure 1 shows the results for one subject in this group.

Subject	Initial Effect (%)	Reversal (%)
ML	77.72	52.36
KM	58.77	27.27
MK	46.02	28.21
MC	28.46	1.26
MR	21.17	5.77
TB	12.17	28.72

Table 1. Change in text entry rate performance between the phases for each subject.

For the remaining three subjects (MC, MR, TB), use of Configuration B had a lower effect on text entry rate relative to baseline (averaging 20% different), and in two cases, a sufficient reversal was not seen on the return to Configuration A. The lack of adequate reversal suggests that some other effect, such as increased skill, rather than system configuration, was primarily responsible for the initial change observed. The right half of Figure 1 shows an example of this for one subject.

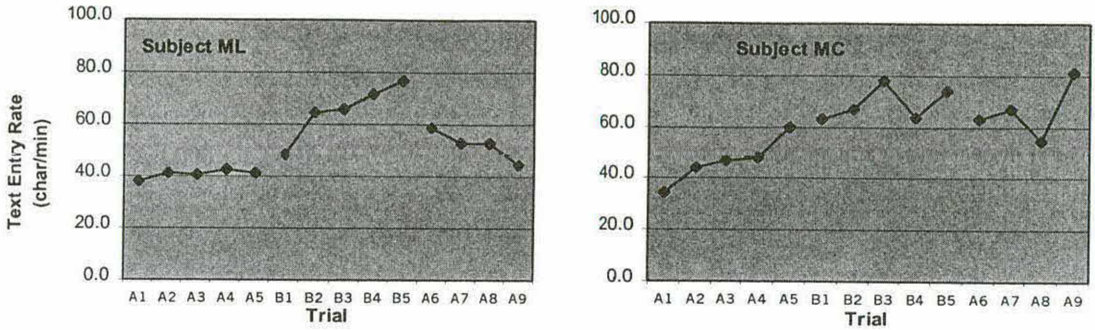

Figure 1. Text entry rate across all trials for two of the six subjects.

DISCUSSION

For some individuals, the configuration of a word prediction system can have a big influence on the resulting text entry rate achieved with the system. This supports the idea of having the system play a role in configuring itself for a given user. One parameter that seemed especially influential was the setting for when the list is displayed. In Configuration A, which is similar to many "default" settings of commercial systems, the list was always on-screen. For most of these subjects, Configuration B delayed the presentation of the prediction list until the user had entered one or more keystrokes. For the faster typists in this subject group, this provided a more advantageous balance between searching and typing, leading to a faster text entry rate. The results suggest that even relatively quick typists (even up to 100 char/min) may benefit from word prediction if the system is configured properly.

The performance of other individuals appears not to be as sensitive to the system configuration. Some people more readily adapt to different configurations. For example, the effect of hiding the list can be mimicked by the user simply ignoring the list during those keystrokes.

The limitations of this study include: relatively few trials per phase, choice of only two configurations for each subject, and natural variation within subjects between the study sessions. A complementary study, also submitted to RESNA 2000, was performed with able-bodied subjects to address at least some of these limitations.

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AAC CORE VOCABULARY ANALYSIS: TOOLS FOR CLINICAL USE

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ABSTRACT

Vocabulary selection is an important component of the augmentative and alternative communication (AAC) service delivery process. Automated language activity monitoring (LAM) provides the quantitative data for identification and analysis of AAC language representation method(s) and vocabulary use patterns. LAM tools to facilitate the analysis of AAC core vocabulary for use with specific individuals or as a tool to develop databases for core vocabulary lists for specific populations are proposed. Implications are significant in the areas of clinical intervention, outcomes measurement, and research.

BACKGROUND

The goal of AAC intervention is to provide the supports and services that result in the most effective communication possible for the individual. Various AAC modalities such as natural speech, vocalizations, gestures, sign, and/or eye gaze may be employed for overall communicative competence. However, communicative effectiveness using assistive technology is accomplished through spontaneous novel utterance generation (SNUG). For people who rely on AAC systems, accomplishing spontaneous, interactive communication or SNUG is highly dependent on random access to core and extended vocabulary.

Vocabulary selection has been a major topic of AAC research. Utterance formulation is contingent upon the selection of vocabulary items to support conversational communication. Differences in age, gender, social roles, and environments are just a few of the factors that influence vocabulary needs. Current techniques used to identify vocabulary needs such as ecological inventories, communication diaries, and team brainstorming are time consuming, cumbersome, and ineffective.

Various investigations have documented the vocabulary-use patterns of individuals in daily environments. These investigations have supported the notion of vocabulary core lists and provide one source to identify core vocabularies for individuals who rely on AAC systems. Vocabulary selection questionnaires based on composite core lists are in development to facilitate this selection process (1). However, an even more efficient vocabulary source than composite lists are word lists compiled from the past performance of the specific individual for whom an AAC system is being developed (2). Unfortunately with past procedures, obtaining and analyzing language samples from AAC users has been difficult, time consuming, and rarely done.

Recent developments in automated AAC language activity monitoring (LAM) provide the opportunity to obtain and analyze AAC language samples. The LAM makes quantitative data on vocabulary use readily available for clinical use. Since LAM data includes language event time stamps, the identification of language representation method (LRM) usage and the association of the LRM to specific vocabulary items is possible (3).

AAC Core Vocabulary Analysis

OBJECTIVE

Quantitative measurement of vocabulary-use patterns of individuals who rely on AAC systems is now practical and efficient with the development of the LAM. Obtaining LAM data allow for analysis of vocabulary diversity including the identification of core and extended vocabulary items as part of the clinical intervention process. However, no automated tools have been available for clinical application and use for outcomes measurement. The objective of this work has been to develop core vocabulary analysis tools for clinical use based on LAM data.

METHOD

This paper proposes procedures and tools for measuring vocabulary use-patterns from individuals who rely on AAC systems based on raw LAM data. Vocabulary diversity may be measured in terms of frequency counts, number of different words, types of words, and word list tables. However, this proposal is based on obtaining language samples from LAM for the specific purpose of identifying core vocabulary usage patterns and frequency counts.

Generally, the first process applied to raw LAM data is the editing of the data into utterances, e.g. "I love chocolate," from the excerpt below. However, the presently proposed tools can be performed without utterance segmentation. First, any pre-stored message is eliminated from the database, since these words would seem to be misleading in calculating spontaneous vocabulary use. Second, the LRM(s) used to select the vocabulary items can be identified. Spelled words are distinguished from predicted words. Once the vocabulary items have been tagged indicating the LRM(s), the clinician can perform various analysis procedures using the core vocabulary analysis tools.

These proposed procedures include: 1) alphabetical listing of the words in the sample with a frequency count; 2) frequency of occurrence listing of the words in the sample; 3) comparing the sample list against a reference list to identify word commonalties or matches; 4) calculating the percentage for sample list matching reference list; 5) alphabetical ordering of word matches and not matches; 6) frequency of occurrence of word matches and not matches. In addition, by tabulating the cumulative occurrence in the frequency of occurrence word listing, identification of core vocabulary is possible.

An excerpt from a narrative language sample using LAM is reported in the following model:

11:14:15 "went "	11:15:48 "I "
11:14:33 "for"	11:15:53 "love "
11:14:41 "des"	11:16:02 "chocolate "
11:14:42 "s"	11:16:57 "yes "
11:14:45 "e"	11:17:03 "but "
11:14:47 "r"	11:17:07 "we "
11:14:50 "t"	11:17:12 "had "
11:15:04 ". "	11:17:20 "tr"

Use of the core vocabulary analysis procedures and tools allows the clinician to review the vocabulary-use patterns contained in this storytelling narrative about attending a concert. Identification of the LRM usage reveals that the individual used Semantic Compaction 83%, spelling 16%, and pre-stored messages 1% of the total utterances. This performance can be compared with pilot study data from high-end users that reveals LRM usage patterns of 93% use of Semantic Compaction, 6% use of spelling, and 1% use of pre-stored messages on AAC systems that provide access to all LRMs.

Use of the proposed tools then allows identification of the words that have been spelled and/or predicted (if word prediction is available). Examples of spelled words from the above language sample include: *over*, *weekend*, *symphony*, *dessert*, *trouble*, *parking*. By running the core vocabulary analysis features, these words can be compared against compiled reference core vocabulary lists or a previous vocabulary list of the individual. With this information the clinician will be able to make decisions regarding vocabulary management. Vocabulary management decisions include answers to these questions: 1) what is core vocabulary for the individual? 2) What is extended vocabulary for the individual? 3) How do both core and extended vocabulary relate to the reference or source list(s)? 4) Are the most effective LRM(s) being used for core?

DISCUSSION

AAC vocabulary selection and management is an ongoing process that must be individualized, dynamic, and periodically revised. Research on AAC vocabulary selection has relied on language sampling of able-bodied individuals to compile word frequency lists for specific populations. Few research studies have compiled word frequency lists from augmented communicators. No research has been based on the performance of augmented communicators who rely on the language representation method(s) supported by today's technology. Consequently, clinicians and augmented communicators have little research to weigh the relative value of vocabulary selection and management decisions.

Fried-Oken and More proposed use of a vocabulary source list and database to study vocabulary selection using formal semantic analysis (4). The core vocabulary analysis tools presented here will provide procedures to compare various source lists, establish a database on various populations, and allow for formal semantic analysis. The cumulative result of the use of these tools will be improved clinical intervention and substantive gains in improved spontaneous, interactive (SNUG) communication of people who rely on AAC.

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EFFECT OF SYSTEM CONFIGURATION ON USER PERFORMANCE WITH WORD PREDICTION: RESULTS FOR ABLE-BODIED USERS

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ABSTRACT

Twelve able-bodied subjects transcribed text using eight different configurations of a word prediction system. None of the individual aspects of the interface had a statistically significant effect on user performance, but there was a noticeable difference between the best and worse configurations.

BACKGROUND

The experiment described in this paper is part of a larger project to develop a word prediction interface that automatically adapts in response to changing user performance and task conditions. A crucial element of a system for adapting word prediction interface parameters (e.g., maximum number of words displayed in the prediction list, minimum number of letters in each word in the prediction list) is a thorough understanding of the effects of parameter choices on user performance.

RESEARCH OBJECTIVES

The experiment described below was undertaken with two objectives:

1. Demonstrate that the configuration of a word prediction system can affect user performance.
2. Determine the relative strength of different parameters as influences on user performance.

More specifically, we were interested in the effects of three different interface parameters (see Table 1) on text entry rate. For each parameter, our goal was to choose two levels that were expected to yield measurable performance differences, while still being clinically reasonable. Predictions of user performance were made on the basis of a user performance model [1] that simulated user interaction with the same word prediction configurations used in the experiment.

Factor	Description	Abbreviation	Level 0	Level 1
A	When list is displayed	S/H	S=1, H=0	S=0, H=3
B	Number of words in word prediction list	Llen	6	2
C	Minimum number of letters in list words	MWS	No minimum	5

Table 1. Interface parameters that were varied during this experiment. S is the number of keystrokes entered per word before the word prediction list is shown. H is the number of keystrokes entered per word before the word prediction list is hidden.

For Factor A (S/H), a main effect of 15 – 20% performance difference was expected. Predictions for the effects of Factors B (Llen) and C (MWS) were more difficult to make. For Llen, the difference was expected to be only 5 – 10%, and when MWS had a value of 5 (Level 1), it was considered possible that the difference could vanish entirely. For MWS, the expected differences were as large as 15%. But the effect was expected to shrink with smaller list sizes (Llen, Level 1).

METHOD

12 able-bodied subjects participated in this experiment. All subjects entered text on the same laptop computer using a mouthstick. Subjects' text entry performance was measured across eight trials, covering all possible combinations of the three experimental factors. Configurations were presented in random order to reduce the confounding influence of learning effects. For each trial, the subject's task was to copy text displayed on the computer screen as quickly as possible while keeping mistakes to a minimum. Subjects had twenty seconds to read each sentence before beginning to type, and only one sentence was displayed at a time. Subjects were encouraged to

search the prediction list each time it appeared on the screen but, in an effort to adhere to real-world conditions, subjects could skip searching the list if they knew the word would not appear - for instance, when entering a four-letter word when the minimum length of words in the word prediction list (MWS) was five letters (Level 1).

The experiment was divided into three sessions. The first session was an orientation and training session that introduced subjects to the experiment and the use of a mouthstick for typing. The training session consisted of four trials of six sentences without word prediction. The second and third sessions began with one practice session of six sentences, with word prediction active, followed by four trials in which the interface configuration was varied using the three factors shown in Table 1. Each trial consisted of a two-sentence warmup followed by a six-sentence test. Both the warmup and the test used the same interface configuration, and the same warmup and test sentences were used for all trials.

RESULTS

The primary measure of interest was text entry rate (TER) for each trial, measured in characters per minute. Data was analyzed using a repeated measures ANOVA, with S/H, Llen, and MWS as the within-subjects factors. Statistical significance was defined as $p < 0.007$ (selected based on the number of comparisons performed per ANOVA).

Figure 1 shows the average performance of test subjects under each configuration, along with standard deviations. As shown in the Figure, the minimum average TER was 60.93 characters per minute (S=0/H=3, Llen=2, MWS=5) and the maximum average was 69.07 characters per minute (S=1/H=0, Llen=6, MWS=5), a 13.4% difference between the slowest and fastest configurations.

Figure 2 shows the main effects for each factor. None of the three factors had a statistically significant effect on TER, although S/H was close ($p < .009$). For S/H, the expected difference between Levels 0 and 1 was 17%, but the actual observed difference was approximately 5%. For Llen, the expected and actual difference between levels was about as large as expected. For MWS, we expected to see a small difference when, in fact, no difference was observed. As can be seen from Figure 2, there was a consistent difference between the predicted and actual subject performance under all configurations. This indicates that the user model overestimated the speed with which subjects would be able to enter text.

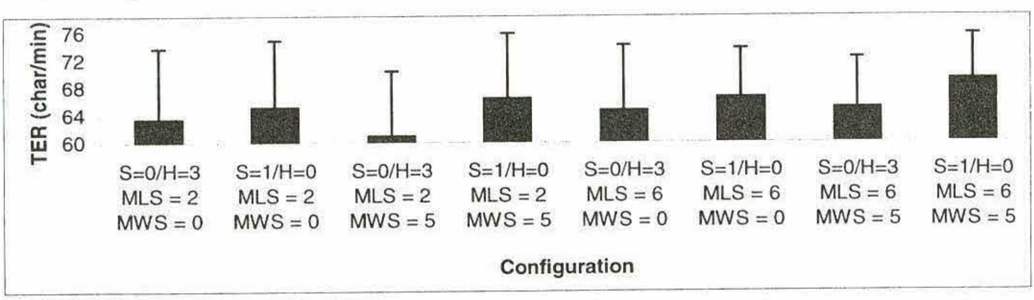

Figure 1. Average Text Generation Rate by Configuration. The chart above shows the average TER for all twelve subjects for each of the eight possible configurations. Error bars indicate standard deviation.

DISCUSSION

The purpose of this study was to examine the effects of the configuration of a word prediction interface on the rate with which subjects enter text. The observed effects were generally in the direction of those predicted, but the magnitude of the effects were not as large as expected for S/H and MWS. As a result, none of the factors demonstrated a statistically significant effect on TER, although there was more than a 10% difference between the fastest and slowest configurations.

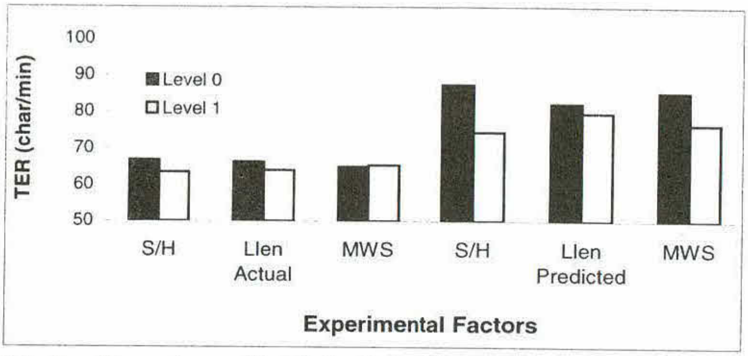

Figure 2. Effect of Interface Parameters on Text Entry Rate. The average text entry rate for all trials and all subjects for each value of the three experimental factors: when the list is displayed (S/H), maximum list length (Llen), minimum word size (MWS). The left side shows the actual data, the right side shows the model predictions.

There were several contributing factors to the difference between the predicted and actual results. Foremost, the predictions were made without specific prior knowledge about the actual subjects (typing speed, list search time, etc.), which makes a difficult task even more challenging. As it turned out, the actual group of subjects was slower than expected. Second, the model assumed a consistent approach to the text entry task when, in fact, the subjects were remarkably adaptive and able to do fairly well under almost any circumstances. For example, the model assumed subjects would always search the list, which was not the case. Subjects sometimes skimmed the list or skipped it altogether if they were confident that the word they were typing was not going to appear in the list, particularly when entering a word that was shorter than MWS.

Finally, the model was too simple to capture certain effects. For example, the rate with which subjects enter keystrokes depends on how much thinking they have to do between keystrokes as well as whether or not they have to search the prediction list. When the word prediction list was displayed after one keystroke and never removed (S/H, Level 0), there was only one keystroke where the word prediction list was not displayed. On the other hand, when the word prediction list was displayed immediately and then removed after three keystrokes (S/H, Level 1), there were often several keystrokes entered without the word prediction list present. Our theory is that keystrokes entered at the beginning of the word (the first keystroke in particular) require more thought than those at the end of the word (despite the fact that the word prediction list was not displayed in either case) because the first keystroke(s) of a word are tied up with initial cognitive processing of the word being entered, while at the end of the word no such processing takes place.

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DESIGNER AAC DEVICE: LIGHTWEIGHT WITH WINDOWS CE

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ABSTRACT

Manufacturers of AAC devices desire to design and develop products that enhance human interactive communication in various modes and allow effective computer access and environmental control. The goals are many; access to powerful language representation methods, functionality, ergonomics, manufacturability and cost effectiveness to the operator. This paper looks at the development of such a device, the considerations taken, the flexibility in design changes and the use of modern tools such as CAD and Solid Modeling.

BACKGROUND

Individuals with CP, ALS, strokes and other conditions have difficulty in communicating with people face to face and via other communication methods. Inaccessibility to environmental control and computers also severely impacts freedom of choice and movement. So a compact device that assists these people and their care-givers in daily life would enhance their quality of life immensely.

STATEMENT OF THE PROBLEM

With so many areas where assistance is desired, and advancing technology with its additional avenues for communication and retrieval of information, a balance is required between functionality, compactness and user-friendliness to make a device effective in daily life. Balancing, too, the aspect of flexibility for the combination and range of disability, with product durability and reliability is also important. Quality of life is intrinsically linked with the quality of assistance given and for practical reasons, must be possible at a reasonable price.

APPROACH

With the design brief established (i.e. functionality, portability and production methods), then physical dimensions and appearances could be entertained. Examining current devices and focusing on the positive aspects of each, ideas could be noted, refined and incorporated. Early designs caused excitement and solidified ideas. However, product releases caused a re-think on the brief. Better displays were readily available - and color too! A re-written brief including Windows CE with the possibility of Internet access was accepted and work started again, but not for long. Always on the lookout to save manufacturing and development costs, an idea came to someone's mind. Could a composite design with a future product be partially incorporated now, thus standardizing parts and quicken the product-to-market time? Being firm and positive in designing achieves a lot, yet being flexible when expediency and dollars prove the greater wisdom, is a must.

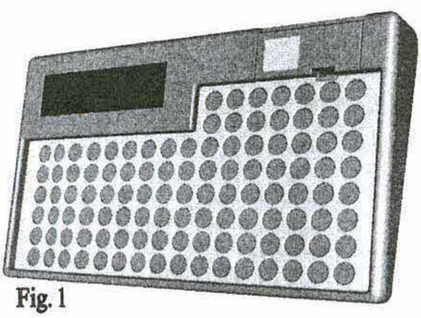
Fig. 1

The keys to successful designing are consultation and experiment. The first requires an open mind, and the second is best served with tools like AutoCad for 2D work and SDRC Ideas Artisan for Solid Modeling of the plastic and rubber parts.

DESIGN and DEVELOPMENT

The initial designs were experimented solely in 3D in Artisan, including applying 'decals' on the model of possible screen displays, graphics and key symbols for company presentations (see figs. 1 & 2).

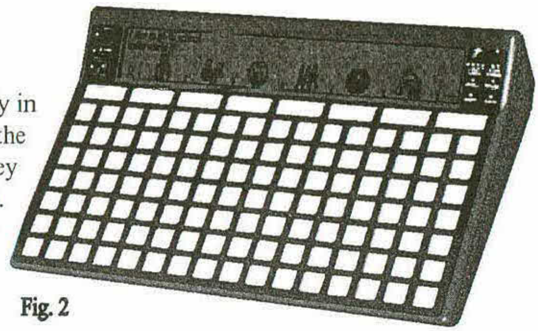

Fig. 2

Various options for the larger color display brief were evaluated in 2D then modeled in 3D. Animation and colored printouts produced good feedback and constructive criticism on both overall design concepts and some interesting details (see figs. 3 & 4). As the new concept grew, so did the components (compact flash, PCMCIA II). Various locations and types of access were experimented with while getting the complete spectrum of human opinion!

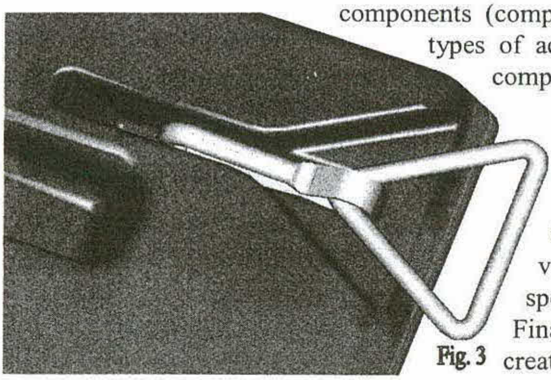

Fig. 3

Initial composite designs were quickly transferred from 2D to 3D with great excitement and positive vibes. But the PCB (printed circuit board) was too small and it had a large hole right in the middle. CAD to the rescue! Dozens of variations in positions and angles of battery, speaker and display were experimented with. Finally, with an idea settled, many 2D sections were created to ensure clearances and functionality of movable parts. Designing the complex case to make the mold as simple as possible was very challenging. Result? A two-piece mold without an expensive slide!

3D construction methodology was established with the initial designs. Then with all the details proven in 2D, the solid model quickly took on a realistic form. Once the top and bottom enclosures were created, STL files were created and e-mailed for rapid prototyping (RP) using Stereolithography (SLA). Within three days (yes, THREE days!) of a purchase order being issued, the 'real McCoy' was physically in our hands. 'Mature, educated' adults suddenly became instant kids with a new toy! Selective Laser Sintering (SLS) was considered for RP, but the material composition was deemed too weak compared with SLA resins to experiment with fitting parts with self-tapping screws.

Once SLA models were approved, silicone molds were ordered and urethane parts popped out with textured surfaces ready for Beta testing. The top still flexed too much. So after some brainstorming, two down-stands were formed in the top enclosure and another SLA set was ordered. Within four days the new SLA parts were received and the design confirmed. Now we were ready for the plastic injection molds to be made.

E-mailed surface data from the 3D models enabled quick quotation. By comparison and inquiry it was discerned that choosing a molder that used modern CNC EDM equipment could save much tooling production

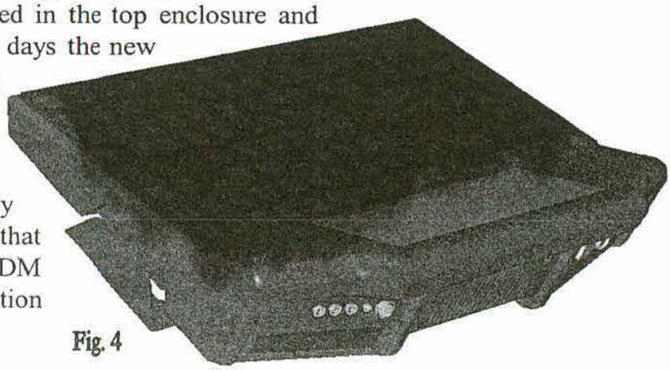

Fig. 4

time and money (in excess of $70,000). Their high standard of orderliness and quality, coupled with their flexibility to handle low volumes suited the company's needs. Because of the open-minded and flexible approach, hand removed inserts are included in the mold to save further expenses in additional machining and handling of stock.

One final use of the 3D model was the detailing of the infrared (IR) windows through the shielding and texturing. The case is made of an IR transparent polycarbonate, so the molder had to know the position of the untextured area, and the spray shop required details of shield masking of four windows within the untextured area. All IR emitter and receiver centers were located in 3D space, and cones were constructed representing the directivity. These were then cut from the case and the resulting holes in the bottom enclosure were used to create elevations and sections for documentation.

EVALUATION

The first analysis of a new design comes from those outside the department within the company and consumer Beta testers. As of paper compilation - "love the shape" is often seen in the reports and heard by those who call in (see figs. 5 & 6). They, and the final market, the long-term operators, are the ultimate judges - not me. And durability? The omens are looking good, and hopefully time will give a flattering report!

DISCUSSION

A well designed product is only as good as the knowledge and application of its components. Tools such as CAD and Solid Modeling are just that - utensils that implement the application of knowledge and design. Nothing replaces the time taken in experimenting or 'playing' with designs to check their feasibility and stir up other ideas. The only difference with modern technology today is that it is cheaper and faster – it is now possible to get a good design, if not the best, in a relatively short period of time and before it goes into final production and out to market. "A bad workman blames his tools", but a good workman uses them well and to the full!

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Fig. 5

Fig. 6

TIDE-ENABL: ENGINEERING DESIGN USING LANGUAGE AND SPEECH

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ABSTRACT

The objective of the ENABL project is to provide access by voice, via speech recognition, to engineering design software. A central technical problem was the implementation of an accessible user interface, using speech recognition, for manipulation of geometric models through speech commands. We developed tools that can be used by engineers who are motorically disabled to the extent that they cannot use their hands, and adapted the system for dysarthric speech.

DESIGN

In the Speech Understanding System, engineering design is accomplished by a dialog between the user and the engineering design system. A "dialog session" is the set of current and all previously-spoken commands; each command is spoken sequentially. The engineering design is built up from the series of spoken commands, such as "Set flap 1 width equal to 400 centimeters" and "Put flap one to side three on right 10." The meaning of each tag string is extracted and stored in an internal dialog table. For example, from the speech command "Put flap one to side three on right 10", a value for the Center X of Flap1 is calculated by the following formula:

$$\text{F 1 CenterX} = \text{P 3 Center X} + \tfrac{1}{2}(\text{P 3 Width}) + \tfrac{1}{2}(\text{F 1 Width}) + 10$$

The values of P 3 Center X, P 3 Width, and F 1 Width are retrieved from the internal dialog table, and a new value for P 3 Center X is stored back into the table. This table is similar in concept to a "spread sheet", that is, the most recently spoken value for each field in the table is available for use in calculations of other values. A graphical representation of the engineering model is then created from the values in the dialog table. An example of the process is shown in Fig. 1.

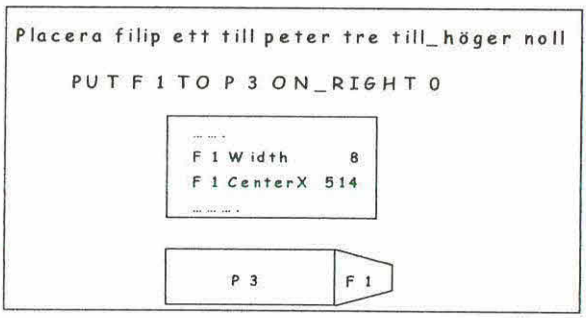

Figure 1. Process of interpreting a speech command. First the spoken words are recognized phonetically and grammatically and converted into a string of semantic tags. These tags are then used for updating the dialog table and generating the engineering graphics.

EVALUATION

Because persons with manual disabilities also often have a vocal disability, a part of the ENABL project is dedicated to evaluating the performance of dysarthric speech on a speech recognition engine. Using a lexicon of approximately 1000 words, a grammar of word class pairs (1) and the monophone acoustic models trained on the normal speech, preliminary recognition experiments were performed. Table 1 shows the recognition results for the 10 dysarthric test persons. Note that for the test persons A1, B, E, R1 and J, the total number of insertions is so great that the accuracy is negative and thus the word error rate (WER) is greater than 100%.

Test persons	A1	A	B	E	K	L	R1	R	T	J
Words correct %	13.3	20	42.7	14.7	60	22.7	21.3	33.3	52	18.7
WER %	145.3	90.7	101.3	124	73.3	82.7	170.7	72	66.7	157.3

Table 1. Correct-word rate and word error rate for 10 dysarthric test persons

This experiment demonstrates the poor performance of an automatic speech recognizer trained on normal speech when dysarthric speech is introduced. Half of the test persons obtained a word error rate greater than 100%, and for 6 test persons, the correct-word rate was lower than 25%.

Correlation between perceptual analysis and speech recognition performance

In this section, perceptual analysis and speech recognition results are brought together for a statistical study. The next graph depicts the correlation between the perceptual intelligibility and the correct-word rate.

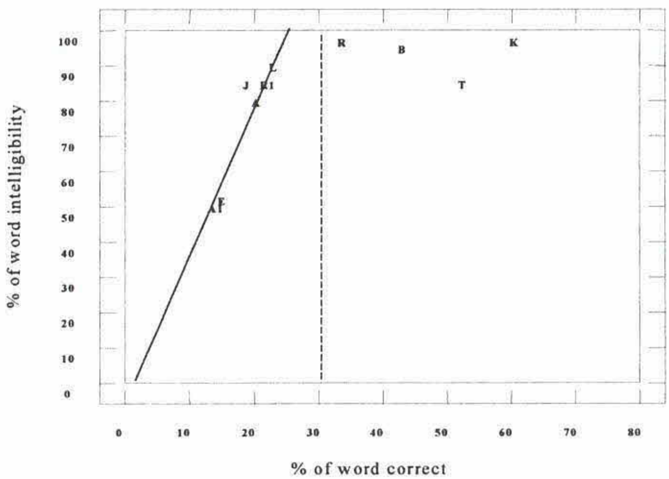

Figure 2. Percent of word intelligibility vs. percent of words recognized correctly

Test persons with low perceptual intelligibility obtain a low percentage of words correct, in fact when the correct-word rate is lower than 30%, the correlation is perfect. This confirms the intuition that if a human cannot understand what a person says, the recognizer cannot either. But if humans can understand clearly what was said (100% or near 100% of word intelligibility), the recognizer does not necessarily understand. On the graph, there are several test persons with very high intelligibility but with various correct-word rates. Those various rates could be due to other factors, for example, the reading speed.

Improving the recognition for dysarthric speech

To improve the recognition performance of dysarthric speech, offline speaker adaptation using maximum likelihood linear regression (MLLR) was performed to create new adapted models (2). MLLR calculates a set of transformations that will reduce the mismatch between the original models and the adaptation material. Here, MLLR is used to adapt the normal-speech-trained acoustic model to dysarthric speech. One test person's (L's) recording was kept as a test set while the other test persons' recordings were used as an adaptation data set. As shown in the next table, different adaptation data sets were used and tested using the recordings of test person L.

Adaptation data set	Words correct %	WER %
Without adaptation	22.7	82.7
Other test persons	40	82.7
Test persons with mild dysarthria	48	69.3
Male test persons	*53*	*66.7*
Male test persons with mild dysarthria	39.4	78.8

Table 2. Recognition results for test person L on adapted acoustic models

Table 2 shows that, in all cases, adaptation improves the results for test person L. The best improvement is obtained when the adaptation set consists of all other test persons of the same gender. This is an encouraging result because the adaptation material consisted of only 5.5 minutes of speech. A larger adaptation set would likely result in an even greater improvement.

The experiments conducted on the recordings of test person L were then extended to all the test persons. Following the best results obtained in the previous experiment, the adaptation set consisted of the rest of the test persons of the same gender. The next table shows the improvement (or degradation) in points of percentage of correct words when using adapted models compared to the original models trained on normal speech. Note that the test persons are ordered (from left to right) from those with less deviant to more deviant speech.

Test persons	R	*K*	B	L	T	E	A	A1	J	*R1*
Gender	F	*M*	F	M	M	M	M	F	F	*F*
Improvement (%)	14.7	*-8*	14.6	30.3	1.6	18.6	18.7	4	5.3	*-1.3*

Table 3. Improvement (or degradation) for the dysarthric test persons using adapted models

Test person L obtained the best improvement, while the results of test persons K and R1 degraded. Test person K is the male speaker with the least deviant speech; the models were adapted using the other male speech, which is more deviant than his. This could explain his degraded results. A similar explanation could be given for R1, who is the female test person with most deviant speech.

For some test persons, the improvement was substantially greater than for others. This raised the question whether the models can be adapted using only dysarthric speech of the same severity and/or same type? More speech material and future work would help to answer this question, but it is clear that the performance of the recognizer on dysarthric speech can be noticeably improved by using adaptation on the acoustic models.

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CARRYING AND ACCESSING AUGMENTATIVE & ALTERNATIVE COMMUNICATION (AAC) DEVICES BY AMBULATORY USERS IN COMMUNITY

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ABSTRACT

Traditional AAC device carrying cases seldom allow ambulatory users with physical impairments to easily access devices when they are in standing position. Enhancing optimal independence to communicate in any possible environment is a priority for AAC clinicians. It is especially important for high functioning users who live in the community and want to maintain an active lifestyle. In this study, a team consisting of an Occupational Therapist, Physical Therapist, Speech Language Pathologist, Ergonomist and vendor developed an AAC device carrying case prototype and this was trialed by six ambulatory users. Changes of functional communication, mobility and balance were the parameters being evaluated and compared to their original carrying methods. This presentation will discuss the outcome of the pilot study.

BACKGROUND

The Augmentative and Alternative Communication (AAC) Clinic of Toronto Rehabilitation Institute (TRI) serves adults with acquired neurological conditions. We have many ambulatory clients with an AAC device who reside in the community. There are several compact portable AAC devices available in the market for these kind of users. Ensuring optimal use of these devices in various communication environments is a challenge for clinicians and users.

Traditional AAC device carrying cases are primarily designed for transportation purposes and do not allow easy access by users. Very often, ambulatory users with physical impairments such as hemiplegia cannot access their devices independently when functional communication is required (For example, asking for help in busy streets or while shopping). One problem identified is that the users require a supportive flat surface to access the device.

RESEARCH QUESTION

This study attempted to find a more effective means of both carrying and accessing the AAC device within the community setting which can enhance optimal independence with communication. To objectively determine the effectiveness, a multi-disciplinary evaluation was employed. The impact of the carrying case on the users' standing balance, walking speed and mobility was assessed by a physiotherapist. The occupational therapist and speech pathologist focused on the changes of functional communication in daily activities. A self rating questionnaire was used to collect users' feedback and comment.

METHOD

The Occupational therapist, Ergonomist, Phyiotherapist, Speech & Language Pathologist and AAC device manufacturer worked together to developed a prototype carrying case It was trialed by six ambulatory AAC users. The prototype was designed to provide a support surface and protection top the device plus easy positioning on the body for transportation. It was built with a light weight polyester material plus an ABS plastic holder. It resembled a backpack with shoulder straps and waist belt but the pouch was in front. It could be opened and adjusted at various angles so as to accommodate users' visual or accessing abilities. The prototype used hooks, D-rings, strings, velcros, straps and belt system to allow optimal adjustability and ease at placement by the users. Throughout the clinical trial, the prototype has gone through several minor revisions.

6 subjects; 4 males and 2 females, participated in the clinical trial of the prototype. They all have acquired neurological condition with onset of more than 2 years. They all live in the community and use portable AAC devices which they directly access. All of the them have an existing carrying case for their devices. To evaluate the impact of the new carrying case on the subjects' functional communication, mobility and balance, standardized assessment batteries and custom developed questionnaires were used. They include:

The Activities Specific Balance Confidence (ABC) Scale
Several of the original questions were adapted to suit AAC users. It contains 11 questions asking the subject to self rate their own confidence level in maintaining balance when doing activities in different situations. The measurement scale ranged from 0% (lowest, no confidence at all) to 100% (highest, fully confident).

Berg Balance Scale
The entire original assessment battery was used. The assessor (a physiotherapist) requested the subject to perform 14 different physical activities. The assessor observed and assigned a score, ranging from 0 (lowest) to 4 (highest), according to his/her balance performance during each activity and 14 separate scores were then completed.

The Gait Speed Measurement
Each subject was asked to walk 20 meters in a straight path on a flat level surface. Walking time was recorded by a stop watch. The gait speed was measured by dividing the recorded time by the 20 meters (second per meter).

Questionnaire evaluating changes of functional communication
A custom questionnaire was developed by the authors which had the subjects evaluate the AAC carrying case in various environments, ease of handling and acceptance of the appearance.

All the subjects were evaluated in 3 different conditions:
Condition 1 - no carrying case or device at all. During this time the subjects acted as their own control group. The collected data established the baseline of normal performance. Condition 2 - Using the original/traditional carrying method. The subjects acted as the experimental group under condition 2. Condition 3 - Using the new carrying case prototype. The users were evaluated after 3 weeks of continual use to ensure complete adjustment. The subjects during this time acted as experimental group under condition 3. Due to the limited amount of subjects involved in the study, the result will not be analyzed statistically and will only provide preliminary information for future investigation.

RESULT & DISCUSSION

Currently, the authors are still collecting the data in condition 3. The results are expected to be completed in January 2000. All quantitative data will be presented in the form of graphs/diagrams for ease of comparison. The qualitative information gathered from the subjects will be summarized in form of tables. The prototype used in this study will be displayed during the session as well.

This pilot study attempts to find a more effective means of both carrying and accessing the AAC device for ambulatory users in the community setting. The results can be used to illustrate the special need for this type of AAC users. We plan to expand this study by acquiring a larger number of participants and including a wider variety of ambulatory client groups in the future. We will also continue to collect suggestions from users and clinicians to work with manufacturer to refine the prototype. Ultimately, it is hoped the carrying case can enhance an optimal communication for these users in the community, work place and school.

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LOGGING AND ANALYSIS OF AUGMENTATIVE COMMUNICATION

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ABSTRACT

Given the complexities of contemporary augmentative communication devices, developing a standardized method for collecting statistics on device usage is of paramount importance. A standard analysis protocol would facilitate objective comparisons between systems, diagnosis of communication impairments, tuning of AAC system parameters to individual users, and design of more effective interfaces. In hopes of fulfilling this need, we have developed a Windows application called ACQUA (for Augmentative Communications Quantitative Analysis) which is capable of computing a wide and easily extensible variety of AAC usage statistics based on logfiles of usage sessions. This package, which will be made freely available once it has been fully tested, has been used to successfully analyze logfiles that comply to an emerging logging standard.

BACKGROUND

Various authors have identified the need for automatic monitoring of augmented communication for the purposes of tuning AAC systems to individual users and providing feedback to the design community [1,2]. This need is exacerbated by the rapidly increasing functionality available in modern AAC systems [1]. The range of language-production related events in these systems includes not only those produced directly by the user – for example, key presses, button clicks, and mouse movements – but also events generated automatically by the device itself – for example, automatic capitalization and spacing, cueing in which a particular element might be momentarily highlighted, dynamic updating of word lists based on context, and automatic abbreviation expansion. To fully exploit usage information for diagnosis, tuning, and optimization, a logging protocol that can represent such events is needed.

Under the auspices the Rehabilitation Engineering Research Center on Communication Enhancement (the AAC-RERC, sponsored by the National Institute on Disability and Rehabilitation Research), we are in the process of defining a general-purpose logging standard for augmentative communication [1,3] (see www.enkidu.net/logfile.html for a complete specification). The ACQUA package has been developed to allow communicators, clinicians, researchers, and manufacturers to quickly extract meaningful performance measures from logfiles conforming to these standards. We have successfully used ACQUA to analyze a large number of logfiles produced by our IMPACT software during two different experiments.

Together, ACQUA and our proposed logfile format constitute a purely software-based approach to the logging and analysis of augmentative communication, which can be contrasted with the hardware-based approach of the Language Activity Monitor (LAM) being developed by Prentke Romich [4]. For dedicated AAC devices which have a serial port, but lack the capability to produce and manage files, the LAM offers an attractive alternative for logging data. Although the LAM logging protocol (consisting of only a timestamp and a text output field) is necessarily less sophisticated than our general purpose logfile format, we are ensuring that ACQUA offers complete support for both formats.

DESIGN

ACQUA is a Windows application which provides a wide range of logfile analysis capabilities through an intuitive graphical user interface. This graphical interface consists of controls and textual fields that allow the user to specify which logfile (or logfiles) to analyze, the specific statistics to be computed, how these measures should be derived, and what to do with the resulting output information. Once the operator is satisfied with the parameter settings, a single button press causes ACQUA to analyze each of the specified logfiles. The analysis results are presented within the graphical interface and may optionally be saved to a space- or tab-delimited file, which may then be used as input to other statistical analysis and data visualization packages (such as Excel and SPSS). Since third-party applications already provide a wide range of generic statistics and visualization functionality, we opted not to replicate these functions – the ACQUA analysis offers only measures that are particularly relevant to augmentative communication.

ACQUA assumes a specific multiple-field format for the logfiles that it analyzes. These fields represent language-production related event parameters including (but not limited to): time of event, human action associated with the event (e.g., button press), textual output (if any) associated with event, and the state of various components of the interface (e.g., list of words present in a word prediction list). The logfile format is flexible in that the subset of all possible fields utilized in any given logfile is variable. The exact sequence of fields is specified in a header contained in the logfile [3]. We hope that this multi-field logging protocol will be adopted as a standard by the industry. Individual manufacturers can then determine which event parameters their systems will be capable of logging.

A wide variety of predefined statistics can be computed by ACQUA. These include raw counts (user selection events, character, words, sentences, deleted character, deleted words, specific keys, etc.) and various calculated ratios (characters per minute, characters per word, words per sentence, selections per word, selections per minute, etc.). Given the appropriate information, ACQUA can also compute keystroke savings by comparing the number of user selections needed to generate a given message (using the AAC configuration that produced the logfile) to the number of keystrokes that would be needed to produce that same message using a baseline configuration – for example, a standard QWERTY keyboard. The operator can select an arbitrary set of specific statistics from a list within ACQUA. Additionally, predefined sets of statistics can be defined, stored to files, and loaded at a later time. Because ACQUA was developed in a modular, object-oriented fashion, adding new statistics can be accomplished rapidly and with a modest programming effort.

Usage statistics can be computed for the logfile as a whole, but can also be computed on a series of consecutive (or overlapping) subsets – or "windows" – to provide a sliding estimate of the specified measures. Windowed statistics can provide the operator with a better sense of the exact circumstances under which a particular augmentative technique or interface is particularly effective (or ineffective). The extent of the window can be based on several different fundamental units, including: elapsed time, number of selection events, number of logfile entries, and number of characters, words, or sentences. The operator can configure the size of the window and the degree of overlap (if any) between consecutive windows. ACQUA's interface allows the operator to rapidly page forward and backward through the data windows to see how the usage statistics change over the course of a single logfile.

In most logfiles there will be significant blocks of time in which there are no entries – time during which the user is either not communicating or is listening to his or her communication partner. To prevent these quiet spans from corrupting rate measures (such as characters per minute), ACQUA includes a variable "pause threshold" parameter. Gaps in the logfile that are longer than the pause threshold are excluded from consideration when computing time-dependent usage statistics. Using a relatively short window can also help to compensate for quiet periods.

EVALUATION

In the course of two empirical investigations of AAC techniques, ACQUA has been used to analyze the efficiency and communication rate of individuals using word prediction systems and an utterance-based output device. In one study, we have used ACQUA to determine the keystroke efficiency of 240 logfiles representing the efforts of 60 subjects over 4 trials. In another ongoing study, we are using ACQUA to analyze the selection efficiency and communication rate of individuals using an utterance-based communication device. In this experiment, we are using the multiple logfile processing capability of ACQUA, allowing us to analyze 40 data files in less than 10 seconds. In both studies, ACQUA's output is fed to Excel and SPSS for more advanced statistical processing.

DISCUSSION

We have described a new software package, ACQUA, for analyzing multiple-field logfiles produced by AAC systems that conform to a proposed logging standard. This Windows-based package provides an intuitive graphical interface, facilitating rapid statistical analysis of logfiles. It is capable of computing a large number of predefined statistics, with a modular structure conducive to the incorporation of new statistics. Comprehensive communication logging and subsequent data analysis – provided by our proposed logfile format and ACQUA, respectively – will be important factors in realizing the full potential of increasingly sophisticated AAC systems.

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DEVELOPMENT OF AN AUGMENTATIVE PORTABLE COMMUNICATION DEVICE

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ABSTRACT

The purpose of this project design was to develop an augmentative portable communication device (APCD) for people who are unable to speak intelligibly. Specifically the APCD was designed to be a wearable vest with voice recording and playback capabilities. Most of the existing portable communication devices that are commercially available are somewhat difficult to operate for those who have limited fine motor skills. Additionally, the existing commercial devices that are easy to activate are generally not very portable. The construction of the APCD has shown that it is possible to build a communication device that is both portable and easy to use by someone with impaired motor skills.

BACKGROUND

There are a plethora of commercial communication devices on the market. There are some are easy to activate, and some that are portable, but there are none that have effectively combined these two features. The portable devices that are available require some degree of dexterity to operate (i.e. small buttons on a handheld device). People without an adequate degree of fine motor control cannot very well hold on to these devices, let alone operate them. For this reason our proposed solution to this problem is to incorporate the communication device into something that the user can wear. Hopefully this new type of device will be able to increase both the mobility and independence of the user, as well as increase their level of self-confidence.

Our goal in designing the augmentative portable communication device (APCD) was to make it useful for those people that have speech impediments, limited fine motor control, and are ambulatory. Our particular APCD was specifically designed for a fifteen-year-old boy named Travis who has cerebral palsy. Travis had several existing augmentative communication devices but none of them were portable and easy to operate. Travis would find any devices with small buttons difficult to operate and would easily become frustrated while attempting the use the device. We worked with his therapists in designing a 'talking' vest that would be easy to operate, and also be compatible with his ambulatory assist device.

STATEMENT OF THE PROBLEM

There were many design considerations that were taken into account while developing the APCD. First, we needed a lightweight, durable vest that incorporated the appropriate circuitry for both message recording and playback capabilities. This circuitry also had to be removable so that the vest could be washed. The wires and circuitry had to be hidden so that the APCD would appear to be a normal looking vest. All the components of the APCD had to be protected from the elements as well as from the user.

Second, the therapists decided that four messages would be a good starting point, so we needed to incorporate four activation areas into the vest. The activation pads needed to be sensitive enough for the user to be able to activate them, yet not too sensitive such that normal movement would activate the messages. Additionally the activation pads, wires, and circuitry had to be placed on the inside of the vest so that vest could be worn comfortably and so that none of the components were exposed to the user.

Third, the recording of the stored messages had to be easy to record and re-record. This is necessary so that the user's therapists, teachers, parents, friends, etc. would be able to record the messages. The message length had to be sufficient enough to record reasonable length phrases and sentences. Finally there needed to be a battery compartment that was easily accessible for battery replacement.

DESIGN

The APCD includes a jeans vest, four activation pads, a speaker, and a box containing the circuitry and a 9V battery. It is a modular design that allows all the components to be removed, interchanged, or replaced. The vest was purchased at a thrift store and then modified by a tailor. Activation of four prerecorded messages is possible through four different activation areas on the vest. These activation areas are custom designed switches about 2 inches by 1 inch in size, that allow pull or press activation for ease of use. The pull actuators are keychains as shown in figure 1, however any object of the user's choice can replace the keychains. It is also possible to remove the keychains and activate the switches simply by pushing on the activation area.

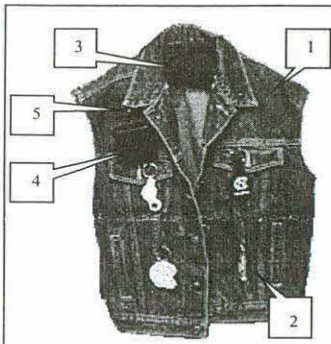

Figure 1. APCD components: 1.vest, 2.activation pad (hidden), 3.controlbox (hidden), 4.speaker, 5.volume controller

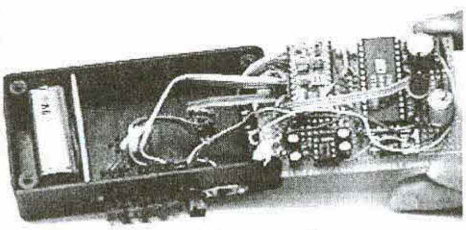
Figure 2. Contents of the control box.

The battery-powered voice recorder and player unit is located in the control box on the upper back of the vest, directly below the collar. The control circuitry is enclosed in a modified commercial polystyrene box. In addition to housing the circuitry (see figure 2), the box also contains a 9V battery, a microphone, a record switch, a LED indicator, activation pad connector plugs, speaker connector plug, RS232C serial port, and a ON/OFF switch. The battery compartment is isolated from the main circuitry and is accessible through a latch that is held in place by a single screw. The integrated circuits inside the control box consists of a microchip audio recorder/player (ISD2560 ChipCorder), a microprocessor (Basic Stamp 2), and an audio amplifier (LM386)[1]. The ISD ChipCorder was set to sample at 8 kHz, which gave this particular chip a maximum record length of 60 seconds[2]. The 60-second capacity was divided into five spaces: four message spaces and a short space for a beep sound. The beep sound is activated when the record session is longer than the allocated space. The Basic Stamp2 microprocessor is a stand-alone microprocessor that has non-volatile memory to store its program. The program is written in BASIC language on a PC and then downloaded to the microprocessor through a serial connection[3]. This makes it very simple to change or modify the control program. On the outside of the control box there is a multifunction LED indicator (see figure 3). When the APCD is initially turned on the LED shines brightly for one second, this confirms that the circuit has proper power. Then it dims and blinks rapidly indicating that it is ready for activation. When a message is playing the LED is on for the duration of the message. Likewise when recording a message the LED stays lit until the recording is stopped. The speaker box located on the outside of the vest was made with a commercial 4 Ω

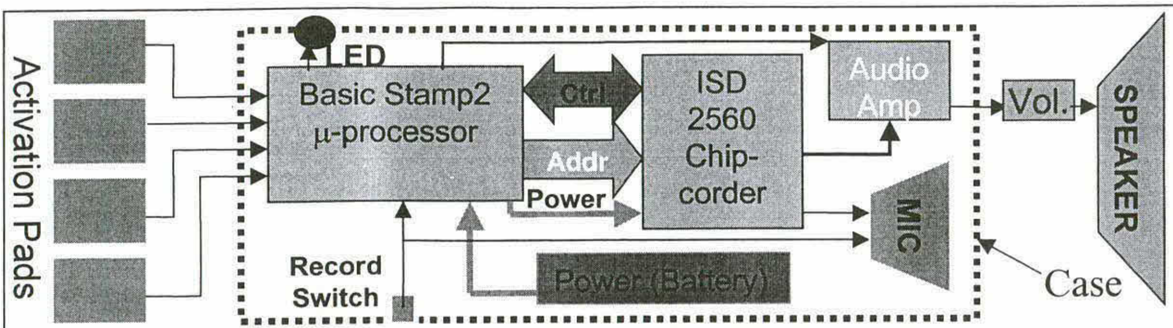

Figure 3. Schematic of Control Box

round (ϕ = 2.25 inch) speaker. The speaker was removed from its original housing and placed in a sturdy polystyrene box. The box was modified to house a female phono connector and a strap holder for a Velcro strap that connects the speaker to the vest. Between the Speaker and the Audio amplifier there is a commercially available volume controller containing an 800 Ω potentiometer, which was modified to match the 4 Ω speaker.

DISCUSSION

The total cost of the APCD was around one hundred dollars, which is fairly reasonable when compared to the cost of other communication devices on the market. When the APCD was initially field tested, it was discovered that there were a few minor bugs with the record function. However these bugs were easily fixed by a simple reprogramming of the microprocessor. The 9V battery was determined to last approximately two weeks with normal usage, which was deemed as acceptable power consumption by the device. After six months of usage the parents of Travis reported that he still actively uses the APCD. In conclusion the APCD has been determined to be an exceptional portable communication tool for ambulatory people with speech impediments or disorders. The APCD, its owner, and the authors have recently been featured in the national news media[4].

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TECHNIQUES FOR AUTOMATICALLY UPDATING SCANNING DELAYS

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ABSTRACT

The communication rate of a person using a traditional single-switch scanning interface is highly dependent upon the inter-group and inter-item delays. We have developed a method for the automatic, real-time adjustment of scanning delays. Based upon quantitative measures of scanning performance such as the frequency of selection errors, the frequency of missed selections, and the portion of the delay utilized for selections, this adjustment scheme rapidly converges on an optimal set of scanning delays. The effectiveness of the technique was verified in a series of experiments.

BACKGROUND

The adjustment of the delays used for single-switch scanning interfaces has traditionally been an ad hoc procedure. Users or clinicians adjust the scanning delays based on approximate performance measures and the user's comfort level. In the course of an extended study on the effects of various scanning variations (e.g., with or without character prediction) on communication rate, we developed a method for dynamically adjusting the scanning delays based on quantitative aspects of user performance. These methods were integrated into our research software suite.

Researchers have suggested various approaches to the optimization of scanning delays, but most can be distilled to a single rule: Decrease delays until the frequency of selection errors becomes unacceptable [1, 2]. For example, in one experiment the scientists stipulated that subjects make fewer than 5% incorrect selections and pass over correct selections less than 10% of the time, adjusting delays manually so as to satisfy these criteria [1]. Adopting a broader set of performance measures, we have developed a method of adjusting scanning delays without human intervention.

APPROACH

We have identified a core set of quantitative measures that indicate the appropriateness of a given scanning delay. These include selection errors, missed selections, missed prediction elements, and selection timing (as described individually below). The augmentative device automatically collects measures in each of these areas over a window of time that is long enough to provide a significant sampling of performance. The system then analyzes this information to determine whether the scanning delays should be increased, decreased, or left unchanged.

We have adopted a proportional delay adjustment scheme in which the delays are multiplied by an adjustment factor whenever a change is required. When the parameters indicate that the delays should be shortened, they are multiplied by an adjustment factor less than one (in our studies, 0.95). Conversely, when the delays are to be increased a factor greater than one is applied (e.g., 1.05).

Selection Errors: The most obvious indication that scanning delays are too short is frequent selection of undesired scanning groups or individual elements. Detecting group selection errors is fairly straightforward. Since most scanning interfaces provide a means to "unselect" groups that are inadvertently selected, the system need only monitor these unselection events. Detecting undesired element selections can be more problematic. We adopted the simple strategy of monitoring the use of isolated backspace or undo selections. Although corrections of this sort do not always indicate a scanning mistake, we found that non-repeated instances of corrections were highly predictive of selection errors. At the expense of system complexity, more reliable indicators could be devised. For example, one could examine the selection that occurred immediately after the correction to ensure that it was close (e.g., next in the scanning procession) to the original (incorrect) selection.

Missed Selections: For most scanning interfaces, if a user misses a selection opportunity, he or she must wait for the scanning focus (cursor) to cycle back around. Missed selections of this sort are especially prevalent for the first one or two scanning groups (i.e., the first couple of rows and the first couple of columns). An excessive number of repeated scanning cycles in a given temporal window generally indicates that the scanning delay should be increased. With many devices, scanning will continue even when the user is not attending to the interface. Although repeated cycles of this type are not informative, positive identification of these situations is difficult. One ad hoc solution is to not count scanning cycles that repeat more than twice.

Missed Prediction Elements: In some of our experimental interfaces, the static character matrix was supplemented by a dynamic character prediction list. This list was scanned character-by-character before proceeding to a row-column scan of the static matrix – an arrangement shown to produce the greatest switch savings [3]. Because the prediction matrix was dynamic, many subjects found that they needed longer delays for the predicted characters than they did for the other characters. If the delays were too short, the scanning focus passed over the desired character before the subjects had time to search for it the prediction list. When this happened the subjects selected the desired character from the static matrix – they missed the prediction element.

A significant frequency of missed prediction elements indicates that the delays used for the dynamic portion of the scanning interface are too short. In the absence of other adjustment indicators (e.g., selection errors or missed selections), only the delays associated with the prediction list need be adjusted. As a practical consideration, however, users may prefer that all delays be adjusted for interface consistency. We considered only missed character predictions in our study, but this adjustment method can extended to handle missed words from word prediction lists.

Selection Timing: The previous adjustment strategies are meant to compensate for various types of selection errors. If these errors occur frequently, the delay should be automatically increased. Conversely, if these errors occur infrequently it may be appropriate to decrease the scanning delays. We have also investigated an alternative strategy for decreasing delays based upon the fraction of the delay utilized during selection. If scanning is too slow for a user, individual selections will occur in the first part of the scanning delay. By analyzing the average fraction of the delay "used up" for each correct selection, we can determine if the delay can be shortened without jeopardizing selection accuracy. If the scanning delay is 2 seconds, but the user is consistently selecting elements only 500 milliseconds after they are first highlighted (25% of the delay), the delay can clearly be reduced. In practice, we found that delays could reliably be reduced without introducing selection errors if the average selection time was less than 65% of the delay.

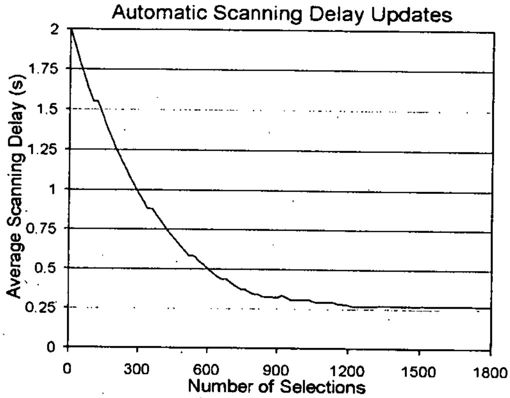
METHOD

All of the automatic adjustment techniques described above were utilized in an experiment in which 15 able-bodied individuals each used two different single-switch scanning interfaces for 15 hours per interface [3]. Subjects were asked to transcribe a series of articles and to respond freely to a collection of non-intrusive written questions. Although the primary focus of the study was the effect of the scanning interface on communication rate, the performance of the dynamic adjustment scheme was an important area of secondary research.

Scanning delays were initially set at 2 seconds. Delay adjustments were based on a window of 20 selections (including corrections). Scanning delays were multiplied by a factor of 1.05 when any one or more of the following conditions were met within the 20 selection window: (1) 3 or more element selection errors (isolated backspaces), (2) 3 or more unselected groups, (3) 3 or more separate repeated scanning cycles, (4) 3 or more missed prediction elements (where applicable). Scanning delays were adjusted by a factor of 0.95 when: (1) none of the preceding criteria were satisfied and (2) the average selection fraction fell below 0.65 (65%).

RESULTS

This plot depicts the average scanning delay as a function of the number of selections for a representative subject. Starting at 2 seconds, the delay drops off quickly, eventually stabilizing at 270 milliseconds. The plot is near- monotonic until the final phase, at which point some mild oscillations occur – the system tries to decrease the scanning delay past the subject's capabilities, only to have it bumped up again in subsequent windows. Although subjects reported problems sustaining fast scanning rates, they did not report noticing the 25 to 50 millisecond oscillations.



DISCUSSION

We have established the effectiveness of a series of dynamic adjustment procedures for scanning delays. Although these techniques were tested on character-based scanning arrays, most should apply equally well to word-based and symbol-based interfaces. Since the proposed adjustment methods rely upon device-collected performance measures (e.g., number of missed selections during a window of 20 selections), most cannot easily be incorporated into current hardware or software communication aids. Given the importance of optimizing scanning delays, however, we hope that manufacturers will begin to adopt these techniques.

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A METHOD FOR OPTIMIZING SINGLE-FINGER KEYBOARDS

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ABSTRACT

The physical arrangement of characters on keyboards contributes to the efficiency and rate at which messages can be generated. While this is true for any individual and any keyboard, character arrangement can have a particularly profound impact on persons with disabilities who utilize only a single finger (or headstick, mouthstick, laser pointer, etc.) for key selection. We propose a new method for optimizing character arrangement on a fixed set of keys, based loosely on the pioneering work of Levine and Goodenough-Trepagnier. By repeatedly swapping the positions of different character pairs (or triplets) and re-evaluating the efficiency of the arrangement, our technique rapidly converges on the most efficient character layout. This method is applicable to any keyboard and can be tailored to the specific motor tendencies of a particular user or class of users.

BACKGROUND

Researchers in augmentative communication have been concerned with efficient keyboard layout for many years [1, 2]. The optimization of character arrangements has recently become important to a broader population as small electronic devices become more prevalent. The arrangement of the traditional qwerty keyboard is (very roughly) optimized for ten-finger typing. On smaller keyboards, where a single finger or stylus is used for typing, this arrangement is very inefficient – it takes a great deal of extraneous movement to generate text. Frequent keys like "a" and "o" are near the edge of the keyboard and common two-letter sequences such as "sh", "sp", and "cl" require selection of keys on opposite sides of the keyboard. Of course, the same inefficiencies confront an augmented communicator who types with a single finger, a headstick, or any other pointing device.

Levine and Goodenough-Trepagnier [1] describe a general methodology to optimize keyboard arrangements for users with specific motor impairments. They focus solely on minimizing the total motor cost associated with using a given arrangement to generate text. Of course, the motor cost of a keyboard is only one consideration in designing a character arrangement appropriate for a particular user. One must also consider cognitive factors, such as the ability of the user to memorize the layout and the intuitiveness of the arrangement. Nevertheless, minimizing the motor cost can represent an important step in the keyboard design process.

We have previously described a method for optimizing the arrangement of letters on an ambiguous keypad which has multiple characters on each key [2] – an interface also addressed in [1]. We have generalized the technique used in our earlier study to optimize character placement on standard (one character per key) keyboards. This rapid optimization procedure reliably produces the minimum cost arrangement for a given set of constraints.

METHOD

We have adopted a simple but effective measure of the motor cost of a given keyboard. First, one defines a motor cost associated with moving from a given key to any other key [1]. This cost is based solely on the keyboard layout and the motor abilities of the user. For an able-bodied person and keys of a fixed size, these key transition costs might just reflect distance between the centers of the keys. For a person with specific motor deficits, or for keyboards with keys of different sizes, a more appropriate set of transition costs would be used. For example, Levine and Goodenough-Trepagnier propose a model in which transition costs are lower along a preferred elliptical axis [1].

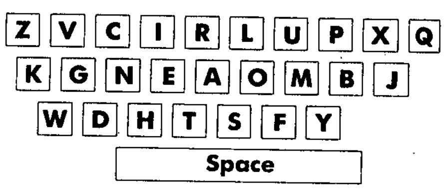
Given a set of transition costs, the total motor cost necessary to produce a representative text can be approximated by summing the cost of each key-to-key transition multiplied by the number of times that transition appeared in the text. To determine the frequency of character-to-character transition, each unique two-character sequence – called a *bigram* – in the reference text must be counted. In our studies, we have derived bigram statistics from a 3 million word text. Given a set of bigram frequencies and key-to-key transition costs, we attempt to minimize the total motor cost required to reproduce the reference text.

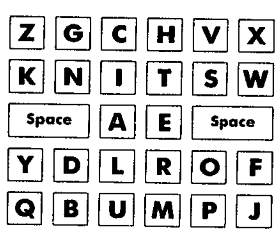
Our optimization scheme is based on earlier work done by our research team for the optimization of ambiguous keypads (like on a telephone) [2], which in turn was inspired by research in the field of operations research [3]. In this approach, characters are initially assigned to random keys. The total motor cost of this arrangement is computed as described above. We then try to decrease the motor cost by systematically re-arranging the characters. This is accomplished by repeatedly selecting pairs of characters and computing whether the cost would increase or decrease if their positions were swapped. The characters are actually swapped only if the cost decreases. Because most of the characters remain in the same position during each rearrangement, determining the relative cost of a two character swap can be done very rapidly by the computer.

After repeating the swapping process many times, the character arrangement will eventually stabilize such that there are no advantageous character swaps remaining. This arrangement may not have the absolute minimum total motor cost, but it will have the best that is possible using the swapping technique given the initial random arrangement. To reduce the impact of the initial arrangement, the optimization procedure is repeated many times with different starting keyboard layouts. Only the final arrangement with the lower total motor cost is retained.

RESULTS

We applied our optimization techniques to a traditional keyboard layout and a modified 6 by 5 grid with enlarged space keys. The motor cost associated with moving between any two keys was assumed to be proportional to the distance between the key centers. The resulting character arrangements, produced in less than one minute on a 300 MHz computer, are depicted below. Compared to a qwerty arrangement, the optimized arrangement on the traditional keyboard reduces the total motor cost by 35.8%. Compared to an alphabetic 6 by 5 grid layout, the optimized grid arrangement reduces the total motor cost by 32.0%. When key-to-key transition costs are biased to reflect specific motor tendencies, even greater gains are possible. For example, if horizontal movements are twice as "expensive" as horizontal movements, the optimized traditional keyboard reduces the total motor cost by more than 40% over a qwerty arrangement.





Our character swapping algorithm is a specific instance of a more general methodology known as *n-optimization* (or *n-opt*) [3]. In this paradigm, one considers the effect of rearranging *n* characters at a time, rather than just swapping 2 characters at a time (a 2-opt approach). The larger the value of *n*, the more likely the final result is the true optimum – the single best possible arrangement. We have subjected the keyboards depicted above to a 3-opt algorithm, in which we repeatedly select character triplets and rearrange the key placement of those characters to minimize total motor cost. This procedure resulted in no changes to the keyboards. As we argue in [1], this is a strong indication that the keyboards are truly optimal with respect to cost. Of course, other practical factors may render alternative arrangements preferable in real-world situations.

Levine and Goodenough-Trepagnier [1] utilized an optimization scheme based on the concepts of genetic algorithms and simulated annealing. Details of the implementation were not provided by the authors, but our results compare very favorably to theirs. The n-opt approach is extremely fast, easy to configure, and gives every evidence of producing truly optimal keyboard arrangements. Note that it is quite possible to combine the two approaches. For optimization problems that involve a more complex user model, a hybrid algorithm may prove most effective.

Although many general-purpose electronic devices (e.g., portable computers, two-way pagers, and electronic organizers) utilize physical keypads or onscreen keyboards, nearly all of these use a traditional qwerty or alphabetic character arrangement. However, *TextWare, Inc.* markets an onscreen keyboard for portable computers that is optimized for single-finger typing, configured in a 6 by 5 grid like the one depicted above. Called the "fitaly" keyboard (from the second row of letters), the motor costs for this arrangement were 2.4% higher than for our "knits" layout.

DISCUSSION

The proposed scheme for the optimization of keyboard arrangements is general enough to be applied to a range of design criteria. The same algorithm can be used to optimize arrangements over different physical key layouts, taking into account the motor tendencies of the target individual or group. Although the total motor cost of a keyboard should not be the sole consideration in selecting a character arrangement, a keyboard designed to minimize these costs can provide an excellent foundation for further refinement.

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A VOICE-ACTIVATED PHONE

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ABSTRACT

A voice-activated phone has been designed for an adult who has limited use of his hands. By using voice commands, this phone can place and receive calls as well as navigate through voice mail systems. The device makes it possible for a person with minimal manual dexterity to use a phone because button pushing is replaced by speaking.

BACKGROUND

The technology behind voice recognition has grown dramatically in this decade. The growth is attributed to the increase in computer processor speeds and new digital signal processing algorithms. Today a computer does not have to be a part of a voice recognition system. Integrated circuits can be purchased which have the ability to recognize and respond to voice inputs.

In January of 1999, Chris Shanahan expressed interest in becoming a client of the Assistive Technology Program at the University of Massachusetts at Lowell. Chris has a desk job in the university's maintenance department. In his position at the university, he must field phone calls but, due to his disabilities, he has great difficulty using a phone. Chris is restricted to life in a wheelchair due to partial paralysis. He has no control of his legs, but has limited use of his arms. Chris can move his arms but not his wrists or fingers.

STATEMENT OF PROBLEM

The goal of this project was to design a voice-activated phone that could be used in an office environment to place and receive phone calls.

RATIONALE

The first phase of this project consisted of a meeting with the client to determine the functionality of the phone. The list of functions was kept basic to insure that the voice-activated phone would do what Chris wanted it to do yet be designed and functioning in a few months. It was decided that the phone would be able to answer an incoming call and place an outgoing call by speaking numbers and words into a microphone.

After the set of specifications was decided upon, the second phase, the research and design phase, began. Throughout the research and design phase there were meetings with the client to discuss progress.

DESIGN

The voice-activated phone consists of three separate entities: a voice recognition system, a telephone, and logic circuitry which connects the two. First, the heart of the system is a HM2007 voice recognition kit. The kit can be trained to recognize and respond to spoken words. To do this the user puts the kit into training mode then speaks a word into a microphone and assigns it a number. Then, when the kit is put into recognition mode, it will recognize a trained word when one is spoken into the microphone and respond by displaying the number that the word was assigned in the training mode. It is this numerical output that propagates through the logic circuitry and acts as a keypress on the phone's keypad.

The second entity of this design is the logic circuitry. The logic circuitry consists of a few integrated circuits and a PAL (programmable array logic). The integrated circuits include decoders, buffers and opto-isolators. These parts are used to route the voice recognition kit's numerical output to the appropriate opto-isolator, which electrically performs a keypress. The PAL is used to check for any errors that occur as a result of the voice recognition kit not recognizing a word. The kit will not recognize a word if there is excessive background noise or if a word did not get properly trained. So the phone will not respond to one of these errors, the PAL detects these errors and shuts off the logic system's output buffers before the errors can propagate to the phone.

Opto-isolators are used in the voice-activated phone's logic circuitry. Opto-isolators are a type of optical switch. When they are turned on, they connect two leads. Since opto-isolators can be used connect two leads the same way pressing a button connects two leads, opto-isolators can be used to simulate pressing buttons. To successfully simulate a button being pressed, the leads on the phone that would be connected when a button is pressed were extended and fed into the opto-isolators. Then, when the opto-isolator was turned on, the leads were connected, simulating the press of a button. The opto-isolators were set up such that the telephone could not tell the difference between a person physically pressing a button to connect two wires and the logic circuit using an opto-isolator to simulate a button being pressed by connecting the same two wires.

The third entity of the voice-activated phone was the phone itself. The phone that was used was one of the standard issue university phones. This phone was used because it was compatible with the university's existing telecommunication network. The phone had a keypad and a set of twelve memory buttons. All of these buttons were interfaced to the logic circuitry and could be "pressed" using voice commands.

DEVELOPMENT

To be sure that the system would work, the logic circuitry was prototyped on a breadboard. After making a few adjustments, the circuit was synthesized on a copper-clad board. Then, the creation of a box to hold the voice recognition kit and the logic circuitry took place. Since the box held the voice recognition kit and the logic circuitry, it had several jacks plugged into it. There was a connection for the microphone, the power cord, and lights to indicate errors.

There was also a keypad connected to the box. Using the keypad is how the user interacts with the voice activation kit. The user uses the keypad to place the voice recognition kit into either training or recognition mode and assign numbers to words that are being trained.

To connect the phone to the logic circuit, leads had to be extended from the phone's keypad to the logic circuit. To do this, the phone was taken apart. Then, the wires that get connected when buttons were pressed were found. Next, leads were soldered onto these wires. Finally, the phone was put back together and the new leads were pulled through a hole in the phone's plastic casing and connected to the logic circuit.

EVALUATION/DISCUSSION

The end product consisted of the phone, a box holding the voice recognition kit and a microphone. The complete product does not take up a large amount of room. The phone is a normal sized desk phone. It is 8x10x5 inches in size. The box has roughly the same footprint and is 4 inches tall. The fact that the phone and the box have the same footprint is important because it allows the phone to be stacked on top of the box. Being able to stack the device avoids wasting desk space.

The voice-activated phone is easy to use. The user first trains the kit to recognize the numbers zero through nine, and the words pound, star, answer, hang-up, and memory. After training, the kit defaults to recognition mode. Then, whenever one of the trained words is spoken into the microphone, the kit recognizes the word and causes the logic circuit to connect appropriate leads, thus simulating a button being pressed or the phone being answered or hung up.

The buttons on the keypad (zero through nine, pound, star) can all be accessed using voice commands. So, for example, saying the word "one" into the microphone causes the number one to be dialed by the phone. Saying the word "answer" causes the phone to answer an incoming phone call by completing a connection that electrically takes the phone off the hook.

Also, the speed dial buttons have been connected to the logic system so they too can be accessed using voice commands. Since the speed dial buttons are accessible, an entire 11-digit phone number can be dialed as a result of one voice command.

The voice-activated phone that was designed costs less than other voice-activated phones. The more expensive phones must be connected to a computer. The computer increases the cost of the phone to well over one thousand dollars while the designed voice-activated phone cost $220 to make.

ACKNOWLEDGEMENTS

The Assistive Technology Program supported the design of the voice-activated phone. The program is funded through grants from the National Science Foundation, corporate sponsors, and private donors. A debt of gratitude is owed to Donn Clark and Alan Rux, two of the faculty members who oversee the program.

Computer Access and Use
(Topic 3)

THE CAMERA MOUSE: PRELIMINARY INVESTIGATION OF AUTOMATED VISUAL TRACKING FOR COMPUTER ACCESS

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ABSTRACT

A system has been developed that uses a camera to visually track the tip of the nose or the tip of a finger or some other selected feature of the body and moves the mouse pointer on the screen accordingly. People without disabilities quickly learn to use the system to spell out messages or play games. People with severe cerebral palsy have tried the system with some initial success. Our goal is to provide computer access to people who are quadriplegic and cannot speak by developing computer vision systems.

BACKGROUND

People who are quadriplegic and nonverbal, for example from cerebral palsy or traumatic brain injury or stroke, have limited motions they can make voluntarily. Some people can move their heads. Some can blink or wink voluntarily. Some can move the eyes or tongue. Family, friends, and other care providers usually detect these motions visually.

Many computer access methods have been developed to help people who are quadriplegic and nonverbal: external switches, devices to detect small muscle movements or eye blinks, head pointers, infrared or near infrared camera based systems to detect eye movements, electrode based systems to measure the angle of the eye in the head, even systems to detect features in EEG. These have helped many people access the computer and have made tremendous improvements in their lives. Still, there are many people with no reliable means to access the computer. We are interested in developing computer vision systems (1) that work under normal lighting to provide computer access to people who are quadriplegic and nonverbal.

STATEMENT OF THE PROBLEM

Develop a system that uses a camera to visually track a feature on a person's face, for example the tip of the nose, and use the movement of the tracked feature to directly control the mouse pointer on a computer.

THE SYSTEM

The system involves two computers: the vision computer, which does the visual tracking, and the user's computer, which runs a special driver and any application software the user wishes to use.

The Vision Computer

The vision computer is a 550 MHz Windows NT machine with a Matrox Meteor-II video capture board. The vision computer receives 30 frames per second from a Sony EVI-D30 camera mounted above or below the monitor of the user's computer. The image used is of size 320 by 240 pixels. The image sequence from the camera is displayed in a window on the vision computer by the visual tracking program.

Initially the operator uses the camera remote control to adjust the pan-tilt-zoom of the camera so that the person's face is centered in the image. The operator uses the mouse to click on a feature in the image to be tracked, perhaps the tip of the user's nose. The vision computer draws a green 15 by 15 pixel square centered on the point clicked and outputs the coordinates of the center of the square. These will be used for the mouse coordinates by the user's computer.

Thirty times per second the vision computer receives a new image from the camera and decides which 15 by 15 square subimage is closest to the previous selected square. The vision computer program examines 400 15 by 15 trial square subimages around the location of the previously selected square. The program calculates the normalized correlation coefficient $r(s,t)$ for the selected subimage s from the previous frame with each trial subimage t in the current frame

$$r(s,t) = \frac{A\sum s(x,y)t(x,y) - \sum s(x,y)\sum t(x,y)}{\sigma_s \sigma_t}$$

where A is the number of pixels in the subimage, namely 225, and

$$\sigma_s = \sqrt{A\sum s(x,y)^2 - (\sum s(x,y))^2} \quad \text{and} \quad \sigma_t = \sqrt{A\sum t(x,y)^2 - (\sum t(x,y))^2}.$$

The trial subimage with the highest normalized correlation coefficient in the current frame is selected. The coordinates of the center of this subimage are sent to the user computer. The process is repeated for each frame.

If the program completely loses the desired feature the operator can intervene and click on the feature in the image and that will become the center of the new selected subimage.

The User's Computer

The user's computer is a Windows 98 machine running a special driver program in the background. The driver program takes the coordinates sent from the vision computer, fits them to the current screen resolution, and then substitutes them for the mouse coordinates in the system. The driver program is based on software developed for the EagleEyes system (2), an electrodes based system that allows for control of the mouse by changing the angle of the eyes in the head.

Any commercial or custom software can be run on the user's computer. The visual tracker acts as the mouse. The NumLock key is used to switch from the regular mouse to the visual tracker and back. The user moves the mouse pointer by moving his head (nose) or finger in space.

The driver program contains adjustments for horizontal and vertical "gain." High gain causes small movements of the head to move the mouse pointer greater distances, though with less accuracy. Adjusting the gain is similar to adjusting the zoom on the camera, but not identical.

Many programs require mouse clicks to select items on the screen. The driver program can be set to generate mouse clicks based on "dwell time." With this feature, if the user keeps the mouse pointer within, typically, a 30 pixel radius for, typically, 0.5 second a mouse click is generated by the driver and received by the application program.

RESULTS

The tracking program works extremely well. The program tracks a person's nose for many minutes without adjustment or intervention. No lighting changes were made in the lab, which has standard overhead fluorescent bulbs. Occasionally the selected subimage creeps along the user's face, for example up and down the nose as the user moves his head. This is hardly noticeable by the user as the movement of the mouse pointer still corresponds closely to the movement of the head.

A person without disabilities has good control very quickly. A person can sit down and spell out a message on an onscreen keyboard after just a minute of practice. Using 0.5 seconds dwell time spelling proceeds at approximately 2 seconds per character, 1.5 seconds to move the pointer to the square with the character and 0.5 seconds to dwell there to select it. People spell out entire messages without intervention by the operator.

We have tried the system with three teenagers with severe disabilities. Two of the teenagers used to have no head control but have had a baclofen pump implanted in the past year to reduce muscle spasticity. They now have some head control and are able to move the cursor around but not yet reliably. One teenager is able to move the cursor at will by moving her head.

We have been working with Rick Hoyt, who was born with severe cerebral palsy. Rick has some voluntary head movement, especially to the left. He and his brother developed an easy to use and increasingly popular spelling system based on just a "yes" movement. We have implemented the spelling system in a computer program (3). When combined with this tracker, messages can be spelled out just by small head movements to the left or right using the Hoyt spelling method.

DISCUSSION

Our current system does not use the tracking history. The subimages in the new frame are compared only to the selected subimage in the previous frame and not, for example, to the original subimage. We plan to investigate methods that would compare the current subimages with past selected subimages, for example using recursive least squares filters or Kalman filters (4).

We are just beginning clinical work with the tracking system. We will invite more people with severe disabilities to try the system. People for whom the system seems appropriate will continue working with it so that we can help them better access the computer and also so we can try to optimize the performance of the system. We will work with Rick Hoyt so he can use the tracking system to spell out messages on the computer using his own spelling method.

Our larger plan is to develop systems to visually recognize the facial movements – head movements, blinks and winks, tongue movements, eye movements (5) – that people with quadriplegia can make so we can provide computer access to as many people as possible. We hope the visual tracker is interesting and useful in itself and a first step in this larger project.

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A SURFACE EMG CONNECTION FOR CURSOR CONTROL AND MORSE CODE

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ABSTRACT

Four subjects with no physical disabilities used a prototype electromyograph (EMG) computer access device to perform text entry using Morse Code. Six subjects with no physical disabilities used the device to perform cursor control for text entry with an on screen keyboard and for graphical user interface (GUI) manipulation. The device is based on the same technology and user interface paradigms used in a Neural Electrode (NE) project. The device performed comparably to alternative access devices which are targeted at a similar level of physical abilities.

BACKGROUND

A patient with an electrode implanted in his brain uses this Neural Electrode to control a computer cursor (1,2). One and a half years after the occurrence of his brain stem stroke he regained some variable EMG activity in his forearm, neck and foot. The recovered EMG signals were amplified and input to the NE signal processing equipment. It was found that the patient had excellent control of the cursor using his EMG signals and used the system to spell on an on-screen keyboard in conjunction with neural signal recordings or with EMG alone. The MM'nM is a three channel integrated prototype of the EMG equipment. Cursor movement is achieved using one muscle for movements in the positive x direction, another muscle for the positive y direction and another for click. EMG signals contain more information than just on/off and it can be used to more directly access a computer. Tonic firing of a muscle (firing at a constant frequency) can be used to extract a position value for a computer cursor. Thus, different cursor positions can be obtained by changing the firing level of the muscles. Phasic firing of EMG (bursts where the rate increases or decreases) can be used to extract a velocity value for the cursor. The bigger the change in frequency of the firing, the faster the cursor will travel. This is the same theoretical basis used in the NE project and the devices will use the same interface paradigms for operating the computer. Patients who become candidates for the NE may learn to use it more rapidly if they first use the MM'nM. The NE would be implanted over the motor cortex corresponding to the muscles used during training with the MM'nM.

Text entry is accomplished with cursor movement overtop of an onscreen keyboard or with one input Morse code. Morse code has not been very popular in the disability field because it initially is highly cognitively demanding, requiring about 20-30 hours of training (3). However, high typing rates can be accomplished when a user becomes proficient with Morse Code and it can become an automatic skill requiring no thought (3). In order to address this issue, Morse code training materials were developed.

RESEARCH QUESTION

Can the MM'nM perform text entry and cursor control at comparable levels to other alternative access devices?

METHOD

Two women and two men, aged 28-48, who have no physical disabilities used the prototype device to test both the Muscle Morse and Muscle Mouse. Two additional females, aged 28 and 40, tested the Muscle Mouse only. Each session followed a similar format where device gain was calibrated at the beginning and sometimes during the session, the subject utilized training materials that are under development, performed timed trials and answered a questionnaire at the end, while the observer documented timing and user mistakes. Additional timed trials were performed using regular keyboard, regular mouse, Muscle Morse, Muscle Mouse, and step scanning for comparisons.

Text Entry using one input Muscle Morse: The muscle used for this test was the thumb flexor of the dominant hand. Lessons to teach and practice codes were compiled from a combination of sources (4,5,6). One pair of related codes were introduced in each lesson along with the related mnemonics which were based on the international communication alphabet. Words used for practice and timed trials were composed only of letters subjects had already learned.

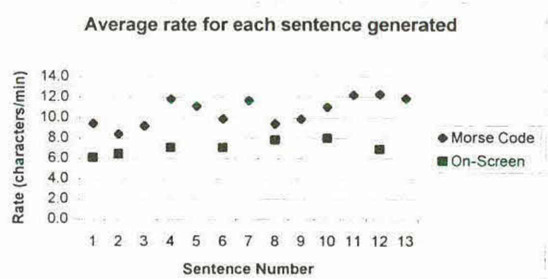
Text Entry using Muscle Mouse: Muscles used for this test were the thumb flexor of the dominant hand for x direction, the other thumb flexor for the y direction and the foot flexor of the dominant leg for mouse click. Cursor movements were in the phasic mode, where increases in tone cause a jump of the cursor in the positive x or y direction. The cursor moves a variable distance based on the time since the last muscle contraction. Techniques to switch to movements in the negative x and y directions are being investigated, for now, the cursor wraps around the screen. WiViK's US SIMPLE on-screen keyboard was used which is in the QWERTY layout arrangement.

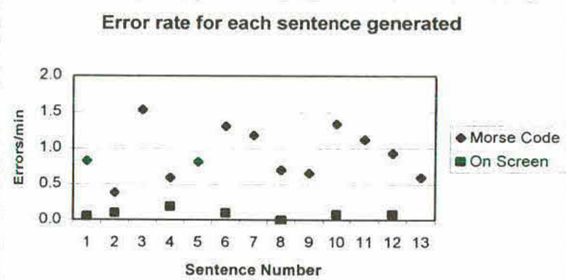
Muscle Mouse in the Windows '95 GUI: The subject was asked to perform a sequence of tasks involving start button, menu bar and windows manipulation.

RESULTS

The questionnaire covered understanding of the text entry interface method, satisfaction/frustration, sense of cognitive effort, physical effort and fatigue. For the most part, subjects felt the same about both text entry methods and the only result with a significant difference was sense of cognitive effort, 5.9 for Morse code versus 3.7 for the on-screen keyboard where 10 indicates the highest cognitive load. Subjects who were already familiar with the international communication alphabet were very successful remembering the codes using the mnemonics.

The average over 13 sentences for Muscle Morse was 10.6 characters/minute (2.1 wpm) with 0.9 errors and over seven sentences with Muscle Mouse was 7.1 characters/minute (1.4 wpm) with 0.1 errors. The following charts show user progression of rate and number of errors.





Timed typing test results	Access Device	Mean Rate (characters/min)	Std. Dev.	Errors/min
* With on-screen keyboard	Regular Keyboard (n=6)	284.5	102.2	1.3
	Regular Mouse* (n=6)	61.9	4.7	0.2
	Step Scanning (n=1)	14.2	2.0	0.3
	Muscle Morse (n=4)	13.2	1.8	1.4
	Muscle Mouse* (n=6)	8.8	2.0	0.2

Average time to complete the GUI tasks was 4 minutes 58 seconds (std. dev. 1 minute 46 seconds) for the first trial, 4 minutes 25 seconds (std. dev. 2 minutes 50 seconds) for the second trial, and 18 seconds (std. dev. 4 seconds) for the regular mouse.

DISCUSSION

Rates using the Muscle Morse 'n Mouse, 2.1 and 1.4 wpm, were compared to regular keyboard and mouse and to those found in the literature for other access devices: HeadMaster from 3 to 10, mouthstick from 4 to 6.6, tongue touch pad 2, and scanning 3.5 wpm (7,8,9,10). The MM'nM rates approach those for scanning and tongue touch pad.

The average rate using the on screen keyboard was slower than with Morse code entry. Most delays in rate occurred because subjects did not use the best strategy to get from one letter to the next, or the subject started moving in the wrong direction first. Thus, the rate can be improved by introducing alternate modes of cursor control, for instance, reverse direction instead of wrap around and cursor return to start position after select. Tonic control over the cursor will be implemented. Users may achieve faster rates with it since proportional information can be extracted from the signal and subjects will not have to repeat a large number of muscle contractions. Keyboard layouts based on frequency of letter usage will also be used to increase rate. Performing small jumps in order to hit very small targets during the GUI trials was very difficult for people to master and a new mode of cursor control is required for that task.

Subjects produced fewer errors using the Muscle Mouse than the Muscle Morse. However, Morse code accuracy did improve over time. The addition of auditory feedback and improvements to the visual feedback display should help users to improve their timing. Use of the mneumonics was very successful for some users and others felt that mnemonics which are self assigned would be more effective. Training materials will incorporate feedback from these trials and be computerized to reduce training time. Two channel Morse code will also be tested since a two input system theoretically allows twice the input rate as a single input system.

Preliminary trials with people who have no physical disabilities indicated that it is worth pursuing this method of access providing improvements to the device and protocol are made.

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SINGLE SWITCH MOUSE EMULATION: A TALE OF TWO METHODS

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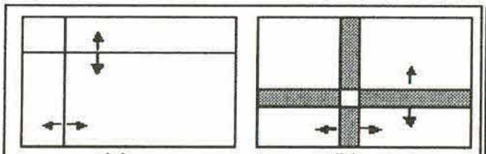
ABSTRACT

This theoretical work compared and contrasted two popular methods used in single switch mouse emulation. The Cartesian method involves selecting the desired row and column. The rotational method involves selecting the desired direction and distance (relative to the centre of rotation). Intuitively the rotational method is a better method to use, since it most closely emulates the task of selecting an object: identifying the target, selecting the direction in which to move, and moving in that direction. In the end, the Cartesian method was shown to be faster over the entire screen when compared the rotational method.

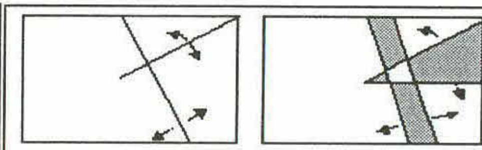
BACKGROUND

Direct manipulation is a screen-oriented means of computer interaction [1]. This interaction style relies upon the use of a pointing device such as a mouse to enable a user to interact with a target object. The direct manipulation style of interaction is used extensively by the Microsoft Windows™ family of products, the Apple Macintosh™ operating system, and many others. The task of direct manipulation can be broken up into three steps: i) identify the target, ii) move to the target, iii) manipulate the target.

There are two general methods used in emulating a mouse with a single switch[2].



(a) (b)
Fig.1
The Cartesian scanning method [2]



(a) (b)
Fig.2
The rotational scanning method [2]

The Cartesian method (Fig.1) requires the user to select a row and column in which the target object resides. This method can be broken up into 5 steps: i) identify target, ii) start scanning (row or column), iii) stop scanning/start next scanning (column or row), iv) stop scanning, v) manipulate target.

The rotational method (Fig.2) requires the user to select the direction in which the object is positioned, and the distance of the object from the centre of rotation. This method can also be broken into 5 steps: i) identify the target, ii) start scanning (direction or distance), iii) stop scanning/start next scanning (distance or direction), iv) stop scanning, v) manipulate target.

To fully emulate a mouse, all areas of the entire screen must be selectable. Furthermore, the resolution should be that of the smallest screen unit, known as a pixel. Accessing the entire screen with this resolution using a single switch can be a time consuming and frustrating process. To reduce this frustration, the fastest and most accurate method of single switch mouse emulation should be used.

RESEARCH QUESTION

The basis of this theoretical work is to determine whether or not a significant difference exists between Cartesian (row, column) and rotational (direction, distance) scanning methods in terms of speed.

METHOD

Given an arbitrary object, O, with its centre at an arbitrary point (p_1, p_2), on a screen of width W and height H, an arbitrary step size Z, an arbitrary scan speed of S, and a constant switch activation time T; which method will arrive at the centre point in the shortest time? Which method will be most accurate?

In order to fully compare the two methods, some assumptions need to be made: i) the times to identify the target is the same for both methods, ii) all points on the screen must be accessible by both methods, iii) the resolution for both methods must be one pixel, iv) each pixel must be available for selection for the same minimum time in both methods, v) the time to manipulate the target is the same for both methods.

The time to get to the point (p_1, p_2) using the Cartesian method can be calculated by the equation:

$$\text{Time} = 3T + (|x - p_1| + |y - p_2|)/Z * S$$

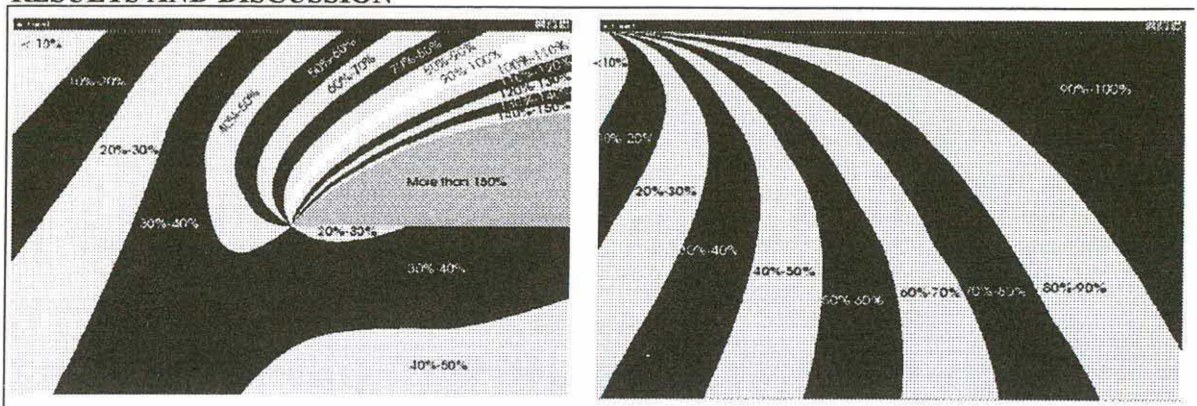
Where x is the starting point of the row selection scan and y is the starting point of the column selection scan.

Calculating the time to get to point (p_1,p_2) using the rotation method is a little more complex. The specific equations to calculate this time have 10 cases for each direction of rotation (clockwise and counter-clockwise), but follow the general equation:

$$\text{Time} = [\theta/Z + \sqrt{(x - p1)^2 + (y - p2)^2}/Z] * S$$

Where θ is the angle of the line joining target point and the centre of rotation, with respect to the starting angle of the rotating line in the direction of rotation; x is the horizontal coordinate of the centre of rotation; y is the vertical coordinate of the centre of rotation.

RESULTS AND DISCUSSION



(a) (b)

Fig. 3

Cartesian Scanning vs. Rotational Scanning: Measured in percentage of time compared to rotational scanning. For example: <10% means that if it takes the rotational method 10 steps to reach a point, then the same point can be reached with 1 step using the Cartesian method (10% of 10). 150% means that if it takes 10 steps to get to a point with the rotation method, it would take 15 steps to get to the same point using the Cartesian method (150% of 10).

Figure 3 (a) shows that when the centre of rotation is in the middle of the screen, the start angle is due West, and the direction of rotation is counter clockwise; it is advantageous to use the rotation method over the Cartesian method for ~17% of the screen. It would appear that the only reason the rotation method has any advantage over the Cartesian method is simply due to the difference in starting points (the Cartesian method in this case starts in the top, left corner).

Figure 3 (b) clearly shows that when the centre of rotation is in the same place as the starting point for the Cartesian method (the top left hand corner), the start angle is due West, and the direction of rotation is clockwise; the rotation method is either the same speed, or slower than the Cartesian method for the entire screen. There is a single line of 1 pixel thickness at the top of the screen where the time is equal for both methods.

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USING THE POWER OF DATABASE SOFTWARE AND DIAL-UP NETWORKING TO PROMOTE THE EMPLOYMENT OF PEOPLE WITH MULTIPLE DISABILITIES

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ABSTRACT

Using a combination of powerful mainstream software, specialized adaptive hardware and software, remote computer networking, and environmental modifications, people with disabilities are becoming more able to work from their homes than ever before. This case study provides an example of combining these tools to enhance the employability of a person whose disability impacts his mobility, motor control, vision, and cognitive processes. It also identifies potential employment opportunities in providing part-time services to small businesses through the use of customized databases.

BACKGROUND

Like a number of people with disabilities, the consumer featured in this case study wishes to be employed but is limited by his inability to work continuously for long blocks of time, complex medical and personal care needs, and transportation difficulties. John (not his real name) has cerebral palsy and rides a power wheelchair. Although he has limited use of his hands, he is able to hit targets with one finger and pick up a piece of paper and hold it up to his one eye that provides him with useful, although limited, vision. He is computer literate and likes to spend time on the Internet. He is very easily distracted, has difficulty with complex tasks—especially when confronted with an unexpected event—and has poor spelling skills. He very much wanted some independent income that he could generate from home on a flexible schedule.

Meanwhile, many small businesses are needing assistance in information processing such as bookkeeping, data entry, and record-keeping. They may not need or want full-time employees and may not have room for them in their offices. This is especially true of home-based entrepreneurs and small service companies.

A job development and support agency under contract with the state Department of Rehabilitation located a potential employer for John: a woman with a process serving business which delivers court summonses, eviction notices, and other legal documents. She had several subcontractors working for her, but did all the extensive and very complex form filling and billing herself, out of her home office. Although she had recently purchased a new computer, she didn't know how to use it, didn't have time to learn, and was always behind in her paperwork. She liked the idea of contracting with a person with a disability to assist her, especially from his home since her own home office was not accessible and she was on the road most of the day.

APPROACH TO THE SOLUTION

There were a number of problems to be solved in the course of linking the consumer with the employer. The employer did not have a clear picture of what she needed, as she had never transferred these tasks to another person before. A lot of discussion went into identifying the nature of the work and her specific needs, along with the best way to transfer information. At the same time, the procedures and methods had to be tailored to John's particular abilities and limitations.

Information Flow

The idea of linking two remote computers is always simpler than the reality, especially when one party is not comfortable with the technology. Fortunately, Windows 98 allows a computer to be set up fairly easily as a host server for a remote machine that connects via the phone line. While a telephone link is relatively slow, it is a good way to transfer files and access a printer attached to the host. Since the employer was not familiar with computers and often needed to send information from the field, we decided that she would fax the information to John. John would process the desired forms, then log onto her computer and print the forms on her printer. They would be waiting for her when she returned home.

Computer Access Accommodating Physical and Sensory Limitations

A number of tools were employed to improve John's access to and efficiency at his computer. These were refined over the course of several months. An IntelliKeys keyboard set at an angle with built-in sticky keys and a keyguard was the main access device for one-finger typing. This was enhanced with a high-visibility custom overlay featuring enlarged, black-on-yellow alphanumeric keys and some specialized macro keys. To further accommodate John's low vision, a 19" monitor and ZoomText screen enlarging software were installed, along with new display settings within Windows that increased the size of icons, menus, and scroll bars. While MouseKeys was initially recommended, John preferred to use a large Microspeed trackball.

John's data-entry rate was enhanced with abbreviation-expansion for frequently-used words and phrases utilizing Abbreviate! software by Words+. Error reduction was addressed both by the use of the keyguard as well as by having the computer echo back each character and word as it is typed. Although this feature is available in ZoomText Level 2, it did not work with the software he was using. Therefore WivVox, marketed by Prentke Romich, was installed.

Despite the fact that handling paper is difficult for John, he doesn't receive the faxes directly into his computer but through a dedicated fax machine. This is largely because he needs all the available screen space to enlarge his data entry forms and switching back and forth between windows is too distracting.

Information Processing Using a Customized Database

The heart of the job involved filling out complex legal forms with information provided by the employer. The forms contained numerous check boxes and sections that had to be filled in based on the type of documents that were served, to whom, by whom, when, and where, and the type of follow-up action taken—a daunting task for most anyone. The challenge was to make this information easy for the employer to convey to John and easy for him to process into the appropriate format. Opportunities for confusion had to be minimized.

Extensive debriefing of the employer revealed a set of ten situations or scenarios that established the way in which the main form was to be filled out and what supplemental forms were needed. These options were very complex to understand but could be easily communicated by a set of codes. Other sections of the forms had a limited number of entry options, such as courthouse names and addresses, or the sets of documents that were served. A system of codes was established for these as well. FileMaker Pro database software was utilized to design a means of translating the codes and conditions into a properly-filled out form.

One database can have many layouts that present the same information in different formats. John opens a data entry layout that has a manageable number of large-sized, large-font, differently-colored field boxes into which he enters the relevant information. His employer faxes him a large-print data sheet with fields that directly match those in his computer layout. The fields contain unique names, addresses, and dates as well as short codes in those fields that have a fixed set of choices. As John copies the faxed data directly into his computer layout, the database warns him when coded entries are not on the list (e.g. non-existent or mistyped codes). Where the choice of codes or options is small, a drop-down selection list is used for speed and to reduce the chance of typing errors.

Some of the codes are linked to information found in "related" but separate database files and are used to generate more complete entries in a different layout of the main database. For example, entering the last 4 digits of a zip code in a field on John's data entry layout automatically enters the city, state, and full zip code in the layout that replicates the complete legal form.

When John is finished entering the data, a click on a button launches several scripts (mini programs) that analyze the various codes and conditions he has entered and use them to put check marks, names, dates, and other information in the proper places on the required forms. In the process, a simple data entry sheet is transformed into finished legal documents. He then logs on to the host computer and initiates a different script that selects the desired versions of the completed forms and prints them out on the printer in the employer's office. The script also enters the completion and transmission dates in a different layout for later reference and billing.

DISCUSSION

While the use of database software to simplify complex tasks is commonplace in the business world, it has great power to be customized to accommodate the particular needs of persons with different disabilities. This is true whether the work takes place in the employer's building, at a networked home computer, or over the Internet.

Existing company databases can usually be modified with the right technical support. The amount of time involved in developing a new database like the one described should not be underestimated, especially if one is not already an expert with all aspects of the software. The person designing the database must have a very good knowledge of the needs and abilities of the intended user as well as the fine points of the job itself. Nevertheless, there is a growing commitment among vocational rehabilitation agencies to find employment for people with multiple disabilities and to provide the necessary resources to promote success. The general trend towards home-based work and non-traditional job structures increases the employment possibilities for persons with disabilities who are not able to work a full shift or who prefer to be working out of their homes. Jobs involving data entry, book keeping, and billing activities particularly lend themselves to the combination of telecommuting and custom-designed databases.

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EVALUATING THE CLINICAL UTILITY OF THE *PIADS* WITH COMPUTER-BASED ASSISTIVE TECHNOLOGY DEVICES USERS

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ABSTRACT

The Psychosocial Impact of Assistive Devices Scale (PIADS) is a quantitative tool that measures the impact of assistive technology devices on quality of life. For the current study, the PIADS was administered in conjunction with a semi-structured interview to a convenience sample of four computer-based assistive technology device (ATD) users. Results are discussed in terms of quantitative and qualitative data. Our conclusion is that the PIADS is a useful tool for measuring computer-based ATD impact, especially when combined with a semi-structured interview.

BACKGROUND

Day and Jutai describe the PIADS as a quantitative tool for evaluating quality of life benefits of ATDs [1]. The PIADS has 26 items that fall within three sub-scales – Competence (12 items), Adaptability (6 items), and Self-Esteem (8 items) – that reflect constructs subsumed under the concept of quality of life. The validity and reliability of the PIADS were established with eyeglass and contact lens wearers [2]. Preliminary studies have been done with wheelchair users [3] and individuals who have amyotrophic lateral sclerosis (ALS) [4]. To date, however, there has been no study of computer-based ATD users.

RESEARCH QUESTIONS

The goals of the current study were two-fold: (i) evaluate the clinical utility of using the PIADS with adaptive computer users, and (ii) identify qualitative correlations between PIADS scores and patterns of device use within users computer-based ATDs.

METHOD

Subjects: The PIADS was administered to a convenience sample (n=4) of consumers who were receiving services from a university-based AT center. The subjects included two males and two females, ranging in age from 38 to 52 years old. The diagnoses included congenital profound low vision, quadriplegia secondary to multiple sclerosis, spastic quadriplegia secondary to cerebral palsy, and arthritis. The range of computer access methods included: a screen magnifier and screen reader with speech output; head-controlled, infrared mouse emulator activating an on-screen keyboard; small footprint keyboard with software access features enabled for single-finger keyboarding; and speech recognition. Two clients were tested prior to their initial AT training, and two clients had at least six months of experience with their systems. All participants had previous experience with other ATDs.

Tools: The PIADS was administered in conjunction with a semi-structured interview. Appendix A includes a list of sample questions that guided the semi-structured interview. Each of the 26 PIADS items is rated on a seven-point Likert scale that denotes the impact of the device on each quality (e.g. –3 indicates maximum negative impact, 0 indicates neutral impact, and +3 indicates maximum positive impact). Each item is scored using a self-rating report by the user.

Procedure: Interviews and PIADS administration occurred at a university-based AT center (n=3) and in the client's home (n=1). In 3 of 4 cases, the PIADS was not administered per its standard protocol due to physical access or vision issues. In these cases, the administrator read the assessment items aloud and marked each of the 26 items as directed by the client. Each client took part in the semi-structured interview, either immediately before (n=2) or immediately after (n=2) administration of the PIADS. All interviews were recorded, transcribed and coded by the first author.

RESULTS

Administration of the PIADS and the semi-structured interview required approximately 60 minutes per client. The sub-scale and total scores for the PIADS are summarized in Table 1.

Table 1: PIADS Data – Average Scores for Three Sub-Scales

Client	Gender	Experience	Intervention	A	C	SE
SM	F	6+ months	HeadMouse / onscreen keyboard	2.3	2.8	2.5
MO	M	6+ months	Reduced footprint keyboard with one-finger access	2.8	2.5	0.9
KO	F	New user	Speech recognition	1.7	2.4	2.4
MT	M	New user	Screen reader with speech output; screen magnifier	2.8	2.1	2.0

Key to Sub-Scale Abbreviations: A=Adaptability C=Competence SE=Self-Esteem

Distinct themes were identified from the interview session for each client and analyzed with respect to their PIADS scores:

SM spoke predominantly about *independence.* She stated: "[The computer has] given me independence and allowed me to function at a much higher level without having to deal with an assistant...My life – other than at the computer – is a series of, actually, humiliation...because I have to have someone do everything for me". She also spoke about the benefits of clinicians respecting her ability to make decisions for herself in regards to technology issues. Upon examining the PIADS ranks for SM, the components which display the highest average level of positive change are within the Competence sub-scale (average rating of 2.8).

MO, who uses his computer for gainful employment, focused his discussion on *opportunity*: "work means contributing to society", "doing one's part", and "work makes me feel good about myself by doing hard work and contributing to the [job] I'm working on". MO stated that without his computer, he would not be employed. He noted his high level of enjoyment and satisfaction he gets out of being able to work in a social environment. MO ranked items within the Adaptability sub-scale highest on average, with an average rating of 2.8 per item.

KO expressed a theme of *productivity*, viewing the computer as a tool to aid her in seeking future employment. KO noted that she could not foresee using the computer for anything other than paid employment. The least positive effect was made in the Adaptability sub-scale (average rating of 1.7 per item).

MT expressed most notably a theme of the computer facilitating an *opportunity* to be able to meet vocational goals. MT stated "I want to be able to show [my co-workers] just how much I know and how well I can do my job". Like MO, MT rated items from the Adaptability sub-scale highest (average of 2.8)

DISCUSSION

The PIADS is relatively quick to administer (15-20 minutes). The semi-structured interview adds a significant amount of time (30-45 minutes), but enhances the PIADS scores by providing anecdotal insights on usability issues, functional outcomes, and service delivery methods. The semi-structured interview helped us understand why clients rated some PIADS items as they did.

The positive themes that emerged from the interviews appear to correlate to PIADS sub-scale averages, however the low number of subjects preclude broader generalization. This area merits further study.

The 26 items on the PIADS are conceptual in nature and somewhat vaguely defined in the testing manual. Some clients required further explanation of test items, which added to the overall time of administration. Even with additional explanation, the PIADS items might be too abstract for some populations (e.g. pediatrics, traumatic brain injury, and developmental delay). The PIADS instructions assume that users will be able to fill out their own sheet, however subjects having vision deficits or manual manipulation deficits require assistance, which introduces a potential source of error.

The instructions for scoring the PIADS do not distinguish between the values –2 and –1, or between +1 and +2. We suggest that the PIADS authors implement one of two changes: (i) reduce the PIADS to a 5-point Likert scale; or (ii) resolve all ambiguities on the existing 7-point scale.

CONCLUSIONS

1. The PIADS provides useful quantitative data about three constructs related to quality of life.
2. Administration of the PIADS is brief enough to be incorporated clinically – either prior to initial ATD training or as part of follow-up.
3. A semi-structured interview elicits functional outcomes issues that add qualitative depth that is complementary to the quantitative information provided by the PIADS.
4. Potentially, the PIADS could be used as a research tool to compare the impact of computer-based ATDs across disability populations and intervention types.

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APPENDIX A: Semi-Structured Interview – Sample Questions

- How often do you use your computer in a given week? Does use vary with time of day/season?
- What do you use your computer to accomplish?
- How did you choose the computer access methods you currently use?
- How did you learn to use your computer access method and computer?
- Have you ever stopped using any assistive technology before? If so, why?
- Are there any hassles or drawbacks with using your computer access methods?

EVALUATION OF NINE IP TELECONFERENCING PRODUCTS

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ABSTRACT

Nine software systems marketed for teleconferencing over the Internet were analyzed with an eye toward applications to telerehabilitation. Practitioners will derive the maximum utility from the new Internet Protocol (IP) conferencing technology, and it will see its optimal development only if manufacturers adhere to standards to ensure product interoperability. The products that claimed to be standard-compliant did, in fact, demonstrate a high degree of interoperability with respect to audio and video communications, but often less so with respect to data-sharing.

BACKGROUND

Data networks have improved in speed and efficiency to the point where they can now satisfactorily accommodate real-time audio and video stream transmissions. A hybrid network of interlaced conventional telephony and IP teleconferencing is fast becoming a reality. The degree to which this new connectivity will allow rehabilitation professionals to expand services to clients at a distance depends on the quality and reliability it can offer. As computers proliferate among the population at large and as more and more homes gain access to the Internet, IP conferencing packages may provide a new and realistic resource for rehabilitation service providers to interact with their clients at a distance.

Teleconferencing packages represent a rapidly expanding class of products marketed for use over the Internet and offer varying combinations of audio, motion video and data communications. In this multimedia context, "data-sharing" includes not only the traditional sense of text exchange, but through the data communications standard, T.120, also opens the opportunity of passing other modes of information between client and rehab professional, including biological signals (e.g., ECG and EMG), a shared whiteboard, and applications (e.g., third-party Windows software for persons with disabilities). The International Telecommunications Union (ITU) recommendation H.323 v.2 is the voluntary industry standard that provides the basis for development, and specifies minimum standards, for audio and call negotiation communications. Video and data communications are optional under the standard but if offered must also adhere to a minimum specified performance.

RESEARCH QUESTION

The analysis here reported, the first in a progression of investigations planned by the Home Care and TeleRehab Technology Center (HCTR Tech Center) at The Catholic University of America, explores the capabilities and limitations of currently available IP teleconferencing technology. Our objective is to lay the foundation for our plan to serve as a resource for practitioners who might employ teleconferencing to an advantage as a tool in their practice.

METHOD

We established three teleconferencing workstations, each able to transmit and receive voice (audio), motion video and data communications. The workstation configuration chosen typified what one might expect to find in a medical center (i.e. fairly up-to-date, LAN-based systems) and in an average home (i.e. a modem-to-POTS (plain old telephone system) Pentium PC system).

We installed a licensed copy of the following IP teleconferencing packages on each evaluation station: Conference (Netscape) 4.0.527; CU-SeeMe Pro (White Pine Software) 4.01.018; Internet Phone 3.1 (Intel) 3.1.0.45; Internet Phone 5.01 (VocalTec) 5.01 build 171; JavaPhone (IBM) 1.2; NetMeeting (Microsoft) 3.01 build 3385; Talk99 (MediaRing) 6.5.005; VDOPhone (VDO Corp.) 3.5 Professional Internet/ITU324; and WebPhone4 (NetSpeak Corporation) 4.02.

We surveyed the features of each teleconferencing package and prepared a comprehensive list of the various features offered by the manufacturers. This included verifying and charting the function of each feature claimed by the manufacturer. Each product was tested for its ability to interoperate with every other product where like functions existed. Each product was tested bidirectionally -- i.e. product A functioned as sender and product B functioned as receiver then their functions reversed. Testing encompassed 36 combinations (72 permutations) of connections in all.

RESULTS

The data intensive nature of our inquiry lent its expression best to chart form not reproducable in its entirety in the limited context of the present document. The full report of our findings is available at http://www.hctr.be.cua.edu/techcenter/contents.htm. To summarize our findings on teleconferencing packages we:

- Present a ***Feature Comparison Chart*** to provide a quick, comparative guide to the products sampled (http://www.hctr.be.cua.edu/techcenter/clean_features.htm). Discrepancies and limitations are noted. ***Product Descriptions***, accessible from this URL, provides specific information on each product sampled, the minimum system requirements to run each package and how to obtain the package software.
- Present the table ***PC-Based Conferencing Product Interoperability (What Works with What)***, http://www.hctr.be.cua.edu/techcenter/works_with.htm, which summarizes the results of interoperability testing.

DISCUSSION

H.323 v.2 Compliance

The manufacturers of all nine products that were sampled are supportive of the concepts underlying the H.323 v.2 standard. This does not, however, guarantee that their products do, in fact, interoperate as they are delivered. Some producers, such as VocalTec, are heavily involved in the H.323 standard process and yet, for this round, produce an admittedly non-compliant product, Internet Phone 5. (Company literature states that the next version of VocalTec's Internet Phone will be an H.323 v.2-compliant package and that they have engaged in interoperability testing of their projected product with other manufacturers such as Microsoft and Intel.) Other companies, such as Netspeak Corporation, have produced a product, WebPhone4, that is, by default, not H.323 compliant but which can be switched into H.323 communication mode via a menu option.

Interoperability

We determined that the packages were intercommunicating only if the stream function was bi-directional for the respective mode (audio, video, data). For example, Netscape Communicator could ring through to the PC running CU-SeeMe but CU-SeeMe couldn't pick up the call and acknowledge back to Communicator. If CU-SeeMe called Communicator, the connection was completed, but no audio or data streams could be passed through. Clearly there is no useable interoperability between such programs. Similarly, JavaPhone could connect with both Internet

Phone 3 (Intel) and Netscape Communicator, but in both cases, audio could flow from JavaPhone to the other application but not vice versa. This was not deemed a useable connection and hence the systems were not listed as interoperable in the interoperability chart.

Thoughts on Feature Utility

Interoperability enhances the utility of a teleconferencing package to a practitioner desiring to communicate with clients at a distance because it expands the pool of possible interactions. Other features that various manufacturers have programmed into their products might also have useful telerehab applications.

Applications collaboration makes it possible for a practitioner to interact with a client in a therapy setting where the client runs a program and the therapist makes adjustments in real-time as the client progresses. For example, following client progress in an exercise to improve reaction time, the therapist could alter the level-of-difficulty parameters of the exercise as deemed appropriate. Collaboration would also allow remote readjustment to in-home monitoring equipment controlled by software on the PC being used for teleconferencing. Other examples under active investigation by the RERC on Telerehabilitation include nursing telesupport (for caregivers of stroke patients) and neurobehavioral training.

The ability to take a snap shot of the client could be useful to a practitioner seeking to maintain a visual record of client status over time, e.g. of a pressure ulcer. Interestingly, not all packages that offer motion video also make a provision to capture a single snap shot.

Multipoint capability allows for the practitioner to bring a third party into the conference. This third party could be, for example, another client, a family member or a consulting practitioner.

A function to allow communication with a regular telephone enhances a teleconferencing program's versatility, as does its ability to communicate via a standard other than H.323 such as H.324 (which covers teleconferencing between PC's over a POTS connection with no intervening Internet transaction). Having the value-added feature of H.324 compatibility in his or her chosen IP teleconferencing software gives the rehab professional the option of communicating with staff in the field who use a stand-alone videophone.

Future Directions: Addressing Quality via Performance Measures

We observed a drop in quality of both audio and video communications for all packages when they were tested LAN to POTS as opposed to LAN to LAN. Future testing will quantify the audio and video output of the various programs. Additionally, we will explore the option of audio stream compression in hardware as opposed to software and will report our findings. We will also explore the effect of various audio *codecs*, compression/decompression algorithms, under different network conditions such as packet loss. Finally, we plan to evaluate various T.120 and NetMeeting data communication features for specific telerehab applications.

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A TOOL TO HELP HUMAN JUDGMENT OF WEB PAGE ACCESSIBILITY

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ABSTRACT

To be accessible to people with disabilities, web pages must conform to accessibility guidelines, but not all conformance can be tested automatically. Human judgment is needed. The WAVE (Web Accessibility Versatile Evaluator) inserts into a web page the textual equivalents seen by screenreaders used by people who are blind, alerts to audio material requiring transcripts or captioning for people who are deaf or hard of hearing, and arrows that show the order in which elements would be read by a screenreader or accessed via alternative keyboards by people with motor disabilities, thus helping a person judge whether the web page is accessible.

BACKGROUND

Web pages present barriers to people with disabilities (tens of millions in the US alone*) if they are not constructed in accordance with guidelines such as those of the Word Wide Web Consortium's Web Accessibility Initiative (WAI) (2). These guidelines include (among other things) requirements that information not accessible to people with disabilities be presented in alternate, accessible forms (e.g. textual replacement for images, and captions or transcripts for audio content); that navigation be possible with alternative input devices; and that pages transform properly when accessed with assistive technology (e.g. material laid out in tables must be read in a sensible order). Software tools such as Bobby (3) are available to check adherence to the WAI guidelines automatically where possible and alert the user to problem areas.

STATEMENT OF PROBLEM AND APPROACH

Automatic checking is not sufficient to check accessibility: human judgment is needed to e.g. evaluate how well alternative forms of information match the original and to determine if reading and keyboard traversal order is satisfactory. But it's difficult or impossible to extract the information needed for this judgment with current browsers and evaluation tools. Our approach was to transform the page to make that information visible.

DESIGN AND DEVELOPMENT

The design is described by the following example, which shows operation of the WAVE software, which was developed with the Perl programming language. Fig. 1 is a web page designed to illustrate several accessibility problems and Fig. 2 is that page transformed by WAVE. The transformed page shows regions (corresponding to table cells that were used for layout in the original). Arrows and numbers indicate the order the regions would be read by a screenreader**. The arrows immediately show a problem with this page: the list which, as shown in Fig. 1, falls under the heading "Take Our Survey" is the 13th region read by a screenreader, so it's quite separated from its heading, which appears in area 3. In other words, a blind person using a

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* Based on statistics from (1) on people with disabilities in the US. These statistics don't explicitly show impact of these disabilities on web accessibility so the "tens of millions" estimate was used.

** Screenreader order assumes a screenreader that linearizes tables (2) screenreader who hears the heading would then hear the text in regions 4, 5, ... 12 before hearing the list. Similarly, the fields in areas 8, 9, and 10 are shown to be separated by their labels in areas 5, 6, and 7. The transformed page also shows that the selectable image at the bottom (area 15) is missing textual equivalents for the selectable areas (labeled "ALT" under "image map") and for the image itself. On the other hand, Fig 2 also shows that an accurate textual alternative is supplied for the scrolling applet at the top (labeled "appl ALT"), and for the image with selectable regions at the top-- except for one area labeled simply "bottom button". Note also that an alert is posted in area 3 that one of the links is an audio file, so the user can play the file and evaluate whether is has content beyond what's displayed in text.

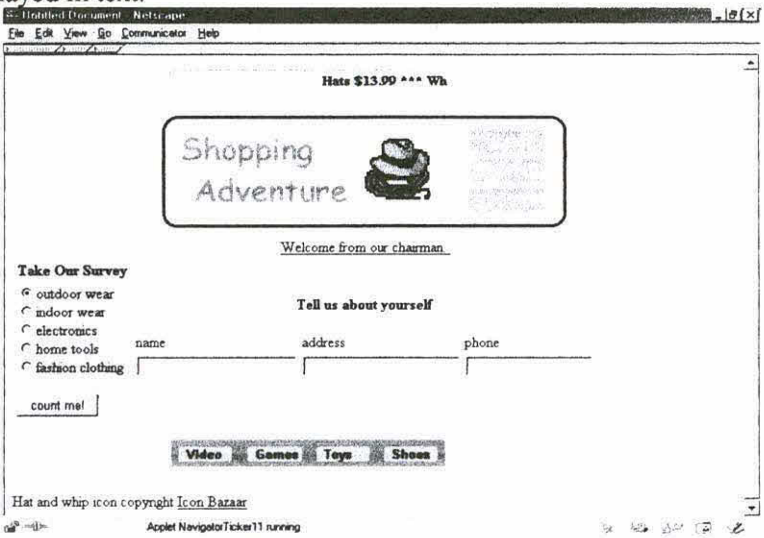

Fig. 1. Example Web Page

EVALUATION AND DISCUSSION

The WAVE has been applied to pages from several commercial sites and results are being shown to potential users to obtain feedback. As of this writing, feedback from potential users is encouraging, and the author is finding it to be a useful way to quickly evaluate a web page. Work is continuing to improve the appearance to reduce clutter, and to add the ability to handle web pages with frames, JavaScript, and other advanced features. The tool shows the benefit of providing convenient access to the information needed to make human judgments of accessibility.

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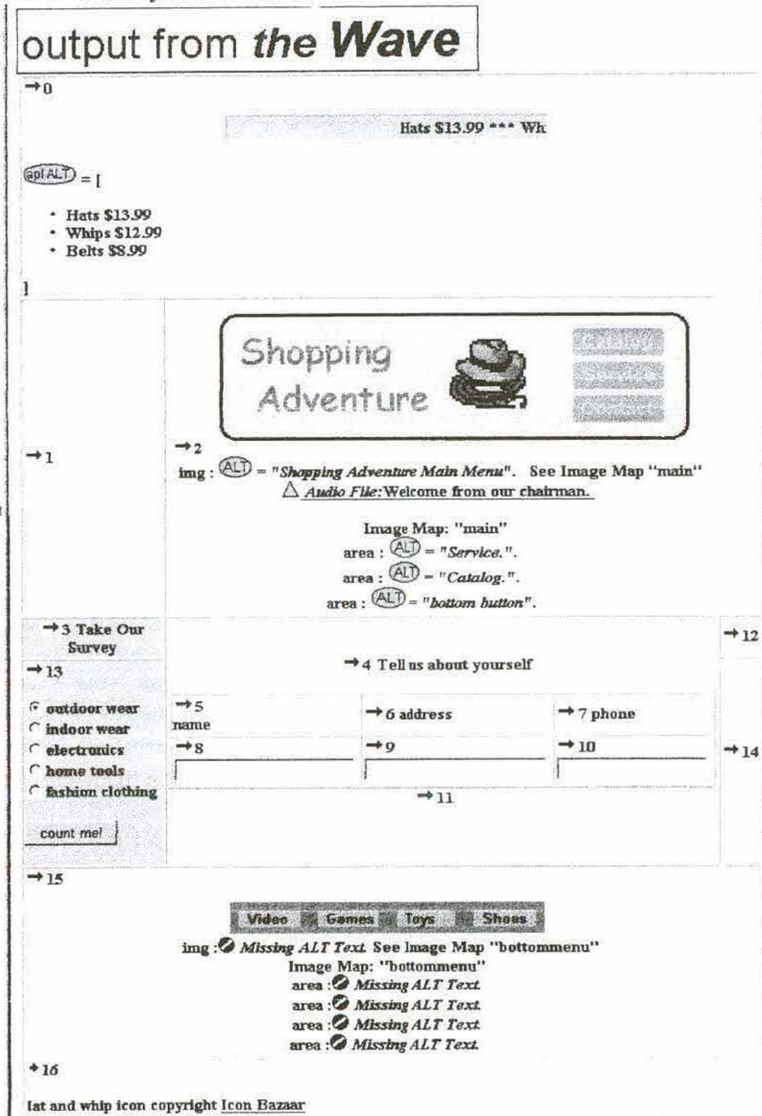

Fig. 2. Web page after processing by the WAVE*

* Hat and whip icon copyright Icon Bazaar, http://www.iconbazaar.com/

Environmental Accommodation
(Topic 4)

CASE STUDY: USE OF LIFT AND TILT PALLET JACKS WITHIN WAREHOUSE OPERATIONS

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ABSTRACT

Within automotive parts distribution centers and many manufacturing facilities, parts are regularly packed and unpacked from large, deep bins. This study focussed on packing small items into triwalls, large bin-like containers constructed of heavy corrugated paper. When placed on the floor, a triwall was approximately 36" high, 47" long, and 41" deep. An intervention trial was conducted in which a lift/tilt pallet jack was introduced. The lift/tilt pallet jack allowed the triwall to be lifted up off the floor and tilted towards the worker. During the intervention trial, systematic evaluations of biomechanics, work posture and worker assessments were completed. Use of the lift/tilt pallet jack greatly reduced biomechanical and posture stress on the low back, but increased biomechanical and posture stress for the shoulder. Workers felt that the device decreased the postural stress associated with their job.

BACKGROUND

This intervention study was conducted within the replacement parts division of a large automobile manufacturer. Distribution centers were organized in a two-tier system. Regional centers filled orders for replacement parts from the service departments of retail car dealers. National centers obtained replacement parts in bulk and replenished the regional centers as needed. Review of injury records covering a three-year period revealed that overexertion injuries were common due to manual materials handling activities and manual packing tasks. Ergonomic evaluations were performed to measure ergonomic stresses for selected work activities suggested by the injury analysis. In addition, ergonomics professionals walked through facilities to understand the ergonomic challenges, and joint labor-management committees from each of the distribution centers identified their top 10 ergonomic concerns. These three sources of information were combined to identify opportunities for ergonomic intervention.

At the end of small parts packaging lines, workers packed corrugated cases and/or plastic bags of varying size and weight into triwalls, large bin-like container constructed of heavy corrugated paper. When placed on the floor, a triwall was approximately 36" high, 47" long, and 41" deep. Triwalls were frequently placed on pallets to facilitate the use of materials handling equipment such as pallet jacks and forklift trucks. This increases the height of the container by 4-5 inches.

The primary ergonomic concern when packing triwalls occured when employees performed low or far reaches in order to position an object in the bottom of an empty triwall. The combination of low working height and a far horizontal reach created high levels of biomechanical and postural strain at the lower back. See Figure 1.

One intervention that was identified was a lift/tilt pallet jack. This device could move pallets loaded with triwalls in and out of packing locations, plus raise and tilt the triwalls (maximum tilt of 90°). See Figure 2. This device raised the triwall lower edge to a vertical height of 31" from the floor, with a maximum vertical height of 73" (top of the triwall). Workers reached over the lift/drive mechanism to pack the triwall, creating a maximum horizontal distance of approximately 40 inches.

Figure 1: Placing corrugated cases into the bottom of a triwall is associated with awkward trunk postures.

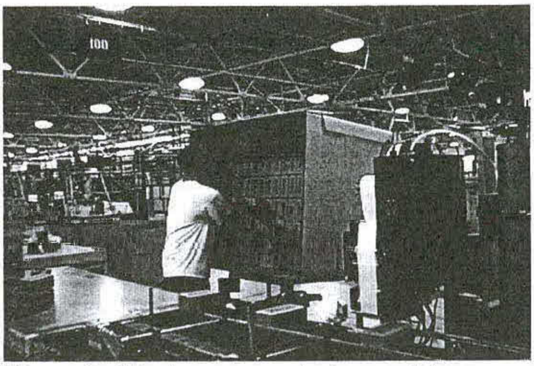

Figure 2: Placing corrugated cases into a triwall positioned on the lift / tilt pallet jack.

METHODS

Three ergonomic analysis methods were used to evaluate this intervention: 1) posture analysis of the trunk and shoulders, 2) biomechanical analysis of the trunk and shoulders and 3) worker interviews. Each of these methods was used to evaluate this job both pre- and post-intervention.

Posture analysis. A computerized posture analysis system was used to measure the amount of time that awkward postures were observed (1). Awkward posture was defined as a significant deviation from the neutral position of a joint. The analyst classified work postures using special computer software while viewing videotapes of work tasks. Torso and shoulder postures were classified using the posture analysis system. Torso posture was classified into 4 categories: 1) neutral, 2) mild flexion (20-45° forward bending), 3) severe flexion (>45° forward bending), and 4) twisted/bent (more than 20° of axial twisting or lateral bending). Shoulder posture was classified into 3 categories: 1) neutral, 2) mild elevation (45-90° angle between upper arm and torso) and 3) severe elevation (>90° angle between upper arm and torso). Various work tasks were videotaped at the work site and were used for these analyses.

Biomechanical analysis. The University of Michigan Three-Dimensional Static Strength Prediction Program™ (2) was used to estimate the back compression force and the joint strength capabilities of a single exertion (e.g. lift, push, pull). The model inputs included anthropometry (worker specific or population percentiles), hand force exerted and work posture. Back compression was used to evaluate strain on the lower back during lifting and other materials handling activities. Back compression was primarily affected by three factors: 1) vertical location of the load, 2) horizontal location of the load, and 3) magnitude (weight) of the load. In general, back compression increased with low vertical work locations because of the need to flex the trunk (stoop) when reaching below the knees. Back compression also increased with greater horizontal reach distance and greater load weight when lifting, due to the larger mechanical moment at the L5/S1 joint.

Worker interview. The worker interview collected demographic information from the participant and then focused on the specific physical demands of the job he / she regularly performed. During the interview workers were asked to assess their perception of the physical job attributes, the most physically-demanding work tasks, seasonal variations in physical stress, and body discomfort.

RESULTS

Torso. The lift/tilt pallet jack provided significant reductions in trunk biomechanical and postural stress. Significant reductions in biomechanical stresses to the trunk occurred when packing at the front and middle zones of the triwall, but only marginal reductions in biomechanical stresses to the trunk when packing at the far horizontal zone. With the triwall on the floor, workers used severe torso flexion (forward bending more than 45 degrees) during eight percent of the work cycle. With the triwall on the lift/tilt pallet jack, severe flexion was completely eliminated. Placing the triwall on the lift/tilt pallet jack allowed the worker to use a neutral posture 95 percent of the work cycle, compared to 84 percent of the cycle when the triwall was on the floor.

Shoulder. Reductions in biomechanical and postural stresses affecting the lower back came at the cost of increases in biomechanical and postural stresses affecting the shoulder. This was due to the fact that workers raised the shoulders in order to reach to higher vertical locations when the triwall was on the lift/tilt pallet jack. With the triwall positioned on the floor, workers could use a neutral shoulder posture (elevation less than 45 degrees) during 95 percent of the work cycle and severe shoulder elevation (more than 90 degrees) occurred for only 1 percent of the work cycle. With the triwall on the lift/tilt pallet jack, neutral shoulder posture was reduced to 84.5 percent of the work cycle, while severe flexion was required for 10.5 percent of the cycle.

Worker Interviews. Twelve workers who loaded triwalls positioned on the floor and five who used the lift/tilt pallet jack were interviewed. There was a significant decrease ($p<0.05$) in worker perceptions of postural strain at the trunk when working with the triwall on the lift/tilt pallet jack.

DISCUSSION

The lift/tilt pallet jack eliminated the worst-case scenario of long horizontal reaches to low vertical locations. Consequently, the biomechanical and postural stresses while packing triwalls were greatly reduced. Due to the configuration of the lift/tilt pallet jack, the maximum ergonomic benefits were realized when it is used in the "full elevation" position where the triwall was raised 31 inches off the floor and tilted 90° toward the operator. Although it was possible to use the lift/tilt pallet jack in an intermediate lift/tilt configuration, obstructions inherent to the lift/tilt pallet jack hardware increased horizontal reach distances and reduced potential ergonomic benefits. For this reason, it is suggested that the lift/tilt pallet jack be used only in the full elevation position when packing triwalls. Changes are being discussed with the vendor to refine the equipment and reduce the horizontal reach distances between the worker and the load point.

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ERGONOMIC EVALUATION OF POTENTIAL JOBS FOR A WORKER WITH BILATERAL WRIST PAIN: A CASE STUDY

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ABSTRACT

Companies are often faced with the problem of finding appropriate jobs for workers with work restrictions or disabilities. A methodology that evaluates the ergonomic risk factors of potential jobs and compares the risk factors with available worker health information to determine the appropriate job assignments is discussed.

BACKGROUND

Decisions about worker placement are typically a medical decision based on information about the worker and the job, and the judgement of a medical professional. However, the physician often doesn't have first hand information about the job. This work aims to provide information about jobs that will facilitate the physician's decision making process and provide increased opportunities for return to work.

To illustrate this work, a case study is presented. The worker presented in this study is a 40 year old female with mild bilateral wrist pain for approximately one year, whose pain has increased within the last 3 months. This 5'2", 230 lb., right-handed worker has been employed in light manufacturing work for 7.5 years, with 7 of those years at her present employer. She currently has work restrictions that limit her lifting to 5 lbs. with either hand, performing no more than 10 gripping/lifting repetitions per hour, and wearing splints whenever working.

Her current employer is a small manufacturing firm that makes emission-sensing units. All jobs are self-paced with relatively long cycle times. Supervisors from the facility identified several potential jobs that they thought would be appropriate for this worker.

OBJECTIVE

The purpose of this study was to determine if the potential jobs identified by the company supervision were indeed appropriate for this worker. A job would be considered appropriate if the ergonomic analysis shows no mismatches when compared to the worker assessment.

METHOD

To evaluate the appropriateness of jobs for a worker, information on both the worker capacities and the demands of potential jobs are needed. Information on the worker was obtained from company medical records, a self-administered questionnaire, and an interview of the worker by a rehab engineer. Information on the potential jobs was obtained from a work site visit and evaluation of the job videorecordings.

During the work site visit, the worker or one of her co-workers was videotaped performing each of the potential jobs. Production rates, cycle times, and total task times were obtained by interviewing the workers performing the jobs. A step-by-step task list for each job was also developed with the help of the worker performing that job. Workplace dimensions, tools, parts, and equipment were recorded.

The information and video obtained during the site visit was used to evaluate each job for ergonomic risk factors. Ergonomic risk factors were evaluated collaboratively by two researchers on a 10-point scale. The 10-point rating scale used verbal anchors with 0 equal to minimal/no stress and 10 equal to maximum/maximal stress. 10-point scales were used to rate repetition and the average and peak forces, contact stresses, and postures for the hand, wrist, forearm, elbow, shoulder, neck, and back.(1, 2)

As part of the University of Michigan Rehabilitation Engineering Research Center's (RERC) research efforts, the worker health information obtained, the information collected on each job, and the videorecordings of the jobs were viewed and discussed by a multidisciplinary team, consisting of rehabilitation and occupational medicine physicians, rehab engineers, and ergonomists. This team considered each potential job to determine if it would be appropriate for the worker within the framework of her work restrictions, established by an outside physician, and the avoidance of potential ergonomic risk factors that might aggravate a wrist condition. Accommodations required for the worker to be able to do the job within the work restrictions given were noted, as were potential modifications that would reduce the physical stresses of the jobs.

RESULTS

A company supervisor identified nine potential jobs for this worker. All of these jobs were documented and analyzed to assess their ergonomic risk factors. Three representative jobs are summarized in Table 1. The information in Table 1 along with available medical data was provided to an occupational medicine physician and a physiatrist at a meeting with the ergonomist and rehab engineer who performed the work site assessment. The ergonomic stress profile and video clips for each job were reviewed. With the exception of peak forearm rotation and elbow elevation, all of the ergonomic exposures were in the low to medium range. Based on this information the physicians concluded that these jobs should be acceptable for a worker with this level of wrist pain, even though some of these jobs entail more than the 10 exertions/hour or require more than the 5 lbs. of peak force specified in the original restriction. These metrics (e.g. repetition) along with the video, provided an integrative view of the job and allowed the medical professional to better assess the job demands. The physicians found the video clips particularly helpful in interpreting the ergonomic stress profiles. Further work will include evaluating and tracking cases to identify critical exposure metrics and the development of a library of examples.

DISCUSSION

The methodology described in this paper is applicable for more than evaluating potential manufacturing jobs for a worker with bilateral wrist pain. The same general method can be used to evaluate the appropriateness of jobs in any occupation for a person with any disability or work restrictions. In order to determine of the appropriateness of a job for a potential worker an ergonomic analysis of the job needs to be conducted (preferably including a work site visit with videotaping) and there needs to be a worker assessment by medical professionals and/or rehabilitation specialists. After job and worker information are obtained they can be compared to determine if there are any mismatches between worker capabilities and job requirements. This method allows the physician to have an overview of the job demands without leaving the clinic. In addition, this method can be used to identify workplace interventions or accommodations when necessary. This procedure can help place workers in jobs which allow them to remain healthy and productive and can help increase return to work opportunities.

More detailed descriptions of the worker and ergonomic assessment procedures can be accessed through the RERC website(3). One of the goals of the RERC is to develop a model system that will allow individuals and groups to perform such assessments. The website includes summaries of the jobs and worker presented in this case study and additional case and job summaries, along with video clips of the various jobs and detailed information when available.

Table 1: Summary of Potential Jobs and Recommendations to Further reduce Ergonomic Stresses

	Filing	Surface Mount Assembly	Solder Flow Machine
Description	File completed orders	Insert board into screen printer, remove board and load in pick and place machine, inspect before and after wave flow machine	Adjust machine to board width, guide boards in one end, walk to other end, and catch boards placing in dishwasher (10-15 boards per load/catch phase)
Cycle Time/ Max. Time per day	< 3 hours/day	30-150 boards/day 4-8 hr/day when running	1-2 hours/day
Repetition	6	3	4
Force (avg., peak)	1, 2	1,2	1,2
Contact Stress (avg., peak)			
Finger/Hand	1,2	1,3	1,2
Wrist/Palm	1,3	2,5	None
Forearm	1,5	2,7 table edge, board caddy	None
Elbow	None	None	None
Posture (avg., peak)			
Wrist Flex/Ext	2,4	1,3	1,4
Wrist Rad/Ul	1,3	1,3	1,1
Forearm	3,8	3,7	3,7
Elbow	2,5	4,5	2,5
Shoulder	3,8	2,3	1,4
Neck	4,5	2,5	3,5
Back	2,3	2,4	1,3
Accommodation required:	None	Provide assistance for set-up (due to lifting restriction)	Set-up done by someone else due to lifting restriction
Potential Modifications:	Music stand on wheels to hold papers to be filed	Use dentist tool with built-up handle rather than tweezers, rearrange carrier edge and pad edge of table	Dishwasher already well modified by placing on raised wheeled platform

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A REFERENCE DESIGN FOR ADDRESSING CROSS-DISABILITY FEDERAL ACCESS REQUIREMENTS

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ABSTRACT

Recent actions by the Federal Congress Access Board and FCC have left industry with a design challenge. The US Congress passed a law saying that all telecommunication products must be readily achievable by people with disabilities where readily achievable. The Access Board and FCC subsequently passed an act of regulations which essentially require that telecommunication products be accessible to individuals with all disabilities (low vision, blindness, hard of hearing, deafness, physical, cognitive and language) and to be compatible with assistive technologies where readily achievable. A major question was: Is it possible to design a standard telecommunication product to address this wide variety of disabilities, and if so is it readily achievable. This reference design effort was carried out to explore this topic. While "readily achievable" is something that only can be determined on a company basis. The design was able to address all of the Access Board/FCC guidelines and to do so using only those technologies which are already in cellular telephones on the market today.

BACKGROUND

The new regulations developed by the US Access Board and passed by the Federal Communications Commission (FCC) essentially require that all telecommunication products be cross-disability accessible whenever this is readily achievable. To date, the only known cross-disability accessible designs were kiosks and voting machines. (These devices were much larger than most telecommunication products and there was serious question as to whether or not accessibility could in fact be built into standard telecommunication products in a readily achievable manner. The objective of this effort was to determine what the limits of "ready achievability" might be for digital cellular telephones at this point in time.

APPROACH

The approach was to limit the technologies used to those which existed in today's cellular phones which are already on the market. The only exception to this was that an assumption was made that the industry would finalize its work on hearing aid compatibility and that the industry proposed "lucent" approach to TTY compatibility were implemented.

RESULTS

The results of the effort are summarized in Table 1. Interestingly, all of the features but one needed for accessibility are mass-market features that would be desirable to the general population. A second generation design is underway which will demonstrate how the access requirements can not only be met with existing technologies but also almost entirely with a set of five general purpose mass market features if implemented properly.

FCC Guideline : Input, control, and mechanical functions	Met?	How the requirements are met.	Cost & Ease of Implementation (If a company had been doing this as a matter of course. e.g. does not include cost of acquainting engineers with access.)
(a) Operable without vision.	yes	Tactile keys and landmarks All input and functions accessible via voice output	- All needed electronics for digitized speech already in today's digital phones; Need only small additions to software and sometimes additional memory (~100k) which will cost little in phones tomorrow. Memory is already available today in many phones (used for digital voice recording). - (This reference design uses spelled speech for transmitted text - voice synthesis will be possible in near future but is not quite practical today for inexpensive phones. Voice synthesis using network facilities is practical today - but is not proposed here.)
(b) Operable with low vision and limited or no hearing.	yes	-Matrix Display - the labels of all buttons can be shown in large print prior to activating them.	Many newer cell phones already use matrix displays. Many have large print displays as standard or as a user setting.
(c) Operable with little or no color perception.	yes	All color coded buttons and indicator lights distinguishable by other means (shape, label)	- Not a problem in most phones today. Any use of color just has to also be accompanied with a text label - as is true on all phone keys today.
(d) Operable without hearing.	yes	Vibration ringer alert. Also buttons have tactile feel of activation (i.e. do not rely on auditory beeps). Visual indication of line status.	- Vibrator is standard in many cell phones. (Not in lower cost phones mostly due to marketing rather than cost.) Visual indication of line status is software only.
(e) Operable with limited manual dexterity.	yes	EZ Access* - buttons can be selected in 2 steps - press desired button then confirm with EZ Button; Dished keys easy to press; Also optional 1-Button mode ; Connection of customized external keyboard.	- Software only for confirm and 1 button access features. (Less than 2k memory.) - Dished keys is no cost, just a different key shape. - Keyboard connection can be via Infra-red or the connector on bottom (Based on industry standard ANSI/TIA/EIA-688)
(f) Operable with limited reach and strength.	yes	Buttons easy to press down; One button mode. Optional Speakerphone is easier for people who cannot place phone to ear; Optional Voice Dialing is faster for some.	- Light button pressure is standard on many phones. Optional speakerphone and voice dialing features are increasingly common - and cost for these features is dropping precipitously. (Speakerphone and voice dialing not required for access in this design).
(g) Operable without time-dependent controls.	yes	Time-outs can be modified via preferences menu	- Menu option. (easily implemented in software)
(h) Operable without speech.	yes	Speech input of commands not required; Text communication modes available.	- Ability to control phone without requiring speech is standard on most all phones. - Text communication is common on digital phones and will be standard soon.
(i) Operable with limited cognitive skills.	yes	EZ Access - all functions accessible via speech output; Also one-button / single number dialing with optional cover plate; Infrared port - allows user programming via simplified step-by-step computer interface	- Speech output of all printed text is already covered above (first item). - One button dialing and single number dialing is software only. - Optional cover plate would cost a bit but is not needed for access. - IR port is standard on many cell phones

Sec. 1193.43 Output, display, and control functions.	Met?	How the requirements are met.	Cost & Ease of Implementation (If a company had been doing this as a matter of course. e.g. does not include cost of acquainting engineers with access.)

(a) Availability of visual information.	yes	EZ Access - all functions and displayed text available via speech	- Cost covered above.
(b) Availability of visual information for low vision .	yes	Matrix Display - all functions and messages shown in large print on display	- A small addition to software to have the phone display the words when it speaks them as discussed above.
(c) Access to moving text.	yes	Arrow buttons - text can be paused or stepped through using arrow buttons - configurable via preferences menu	- Preferences menu option (easily implemented in software)
(d) Availability of auditory information.	yes	Ringing tones, beeps shown on display (and vibrating ringer). TTY messages shown on display. Speech to Text available via relay services. VCO supported.	- Using the Lucent solution strategy (or final standard), TTY codes can be decoded in digital phones using software. A little additional software would allow TTY text to be displayed. - All other sounds made by the phone can be visually displayed as well using existing displays.
(e) Availability of auditory information for people who are hard of hearing.	yes	Full FCC volume range.	- Cell phones already exist that meet the FCC specified levels
(f) Prevention of visually-induced seizures.	yes	Flashing lights all within acceptable flash frequencies.	- No cost. Not a problem on most phones today.
(g) Availability of audio cutoff.	yes	Headset being placed in jack cuts off the speaker	- Standard industry practice.
(h) Non-interference with hearing technologies.	yes	Per Standards group ANSI C63	- Already being addressed by industry.
(i) Hearing aid coupling.	yes	Hearing aid t-coil compatibility	- Already common in many phones including world's smallest mass market cell phone.

FCC Guideline Sec. 1193.51 Compatibility	**Met?**	**How the requirements are met.**	**Cost & Ease of Implementation (If a company had been doing this as a matter of course. e.g. does not include cost of acquainting engineers with access.)**
(a) External electronic access to all information and control mechanisms.	yes	Infrared port allows activation of all features remotely.	- Already common in many cell phones (including Nokia's most popular model). Only software protocol needs to be added.
(b) Connection point for external audio processing devices.	yes	Standard subminiature headset jack connects to external auditory processing devices	- Hardware for this is already used by most cell phone companies for connection of headsets (including world's smallest mass market cell phon). - No cost to use standard signal levels.
(c) Compatibility of controls with prosthetics.	yes	Keys do not require contact with human body to work. Dished keys make it easier to press keys for people with limited manipulation.	- Not aware of any phones that fail this guideline today (though there probably is one). - Most (non-cell) phones also have dished keys like the old touchtone phones.
(d) TTY connectability.	yes	Headset jack is a TTY connector	- Headset jack already used as TTY connector today for some TTYs. (see also next item)
(e) TTY signal compatibility.	yes	Phone can send and receive TTY signals.	- One of 3 industry proposed all software solutions is used. (which work with today's phones.)

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AN ANALYSIS OF PRODUCT DESIGN EVALUATION AND RECOGNITION PROGRAMS

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ABSTRACT

In preparation for possibly creating a new universal design recognition program, this project reviewed thirty-nine product design evaluation and recognition programs currently or previously in use. Four types of programs were identified: design award programs, performance-based programs, standardized compliance organizations, and endorsement or "seal of approval" programs. Based on the findings, the authors plan first to explore opportunities to infuse the Universal Design Performance Measures developed through this project into existing programs rather than create a new program.

BACKGROUND

The authors are conducting a three-year field-initiated project, funded by the National Institute on Disability and Rehabilitation Research (NIDRR), titled "Promoting the Practice of Universal Design." The purpose of the project is to increase the acceptance and adoption of the universal design approach by mainstream product industries. One project task is to explore the possibility of establishing a universal design recognition or certification program based on results of a product evaluation protocol being developed by the project.

RESEARCH QUESTIONS

This paper describes a research effort undertaken as part of the project to review evaluation and recognition programs currently or previously in use, to determine their purposes, methodologies, and levels of success. In preparation for possibly creating a new program recognizing universal design achievement, the intent of this task was to study the structures and effectiveness of existing systems in achieving their purposes and to study the reasons some recognition systems failed or are no longer in use.

METHOD

Thirty-nine product evaluation programs were reviewed. Sources of information included professional journals, mainstream publications, Internet sites, and professional and technical organizations.

RESULTS

Four types of programs were identified: design award programs, performance-based programs, standardized compliance organizations, and endorsement or "seal of approval" programs. The major differences among these programs centered on the product evaluation protocol. Protocols in use ranged from soliciting opinions of invited judges to measuring performance against rigorous engineering specifications.

Design Award Programs

The ten design award programs reviewed claimed to recognize design excellence, based on the opinions of expert judges. Criteria for "excellence" were often very general and dependent on the composition of the panel of judges, which changed from year to year.

The judging period is usually very brief, allowing judges a minimum of experience with each entry. Design award competitions may include cash prizes, such as with the *Maddak Awards* (1). More often, these awards are created to enhance the prestige of the design firm and/or the client. The Industrial Designers Society of America's *Industrial Design Excellence Awards* (2), for example, are the subject of a special annual issue of "Business Week" magazine. The *Good Design Award,* established in 1957, described itself as the "world's oldest design competition" (3).

Performance-Based Programs

Twelve performance-based programs were reviewed which introduce another level of detail to the evaluation of products. Each program applied standardized guidelines for performance in actual use. In some cases, such as at Consumers Union, professional testing staff developed creative, specific tests for a product being tested, such as the "gorilla," a huge tumbler built exclusively for testing the durability of luggage (4). The ProMatura Group's Institute for Technology Development used a select panel of consumers to test products and the manufacturers' claims (5), as did Consumers Union, on occasion.

The U.S. Access Board used a panel of professional and consumer experts to establish performance guidelines for telecommunications devices (6). Unlike engineering specifications, these guidelines enabled designers to explore a variety of approaches to meet performance requirements.

Standardized Compliance Organizations

Eight standardized compliance organizations [e.g., American National Standards Institute (ANSI), Occupational Safety and Health Administration (OSHA), Underwriters Laboratories, Inc. (UL)] were reviewed under this project. These organizations generally apply the most rigorous scientific testing procedures, and failure to comply with their standards may restrict a product from the marketplace. The testing protocols of these organizations are recognized and applied worldwide, and products marketed in many countries must comply with them.

The requirements of compliance organizations are most familiar to designers, but poorly understood by consumers. A seal indicating compliance with these organizations' standards generally means the product is "safe," though not necessarily easy to use, or even useful.

Endorsement or "Seal of Approval" Programs

Eight of the programs reviewed were institutional endorsement or "seal of approval" programs. These programs varied widely in the nature of their testing and the standardization of evaluation criteria. All used some form of testing panel. The American Dental Association maintained that 100 consultants reviewed and tested products (7). The Good Housekeeping Institute stated that it employed 40 staff to test products and evaluate advertising claims (8). The American Medical Association (AMA) discontinued its program in response to media allegations that endorsement had been simply "purchased" by some companies through a donation to the AMA (7).

Although seals are often prominent on product packaging, the meaning of endorsement by these organizations is not always well understood by consumers. For example, few consumers are aware that the *Good Housekeeping Seal,* which has existed for 88 years, entitles the purchaser to a replacement or refund from Good Housekeeping if a product bearing the seal proves defective within two years of purchase(8).

DISCUSSION

Of the total of 39 programs reviewed, nearly half (17 programs) recognized, in various forms and to varying degrees, usability for older adults and people with disabilities. This was both surprising and encouraging, even if the criteria applied to the evaluation of usability for seniors and people with disabilities were far from uniform. Recognizing their limitations in this area, some of these programs have, in fact, sought assistance. For this reason, there may be an excellent opportunity to work within these programs to develop and apply the Universal Design Performance Measures being developed in another task of this project (9).

Based on the findings of the research described in this paper, the authors believe that establishment of a unique recognition program for universal design should not be pursued at this time. Instead, project efforts should first explore opportunities to share with and infuse into existing programs the Universal Design Performance Measures developed through this project. In this way, project results may have the maximum impact and reach.

The authors suggest that those 17 design evaluation and recognition programs that already consider usability for seniors and people with disabilities be approached first. Upon completion of the testing of the Performance Measures with designers and consumer households currently underway, these documents may be shared with administrators of the 17 programs, with the intent of establishing collaborations and partnerships in recognizing and promoting universal design.

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PROGRESS IN THE DEVELOPMENT OF UNIVERSAL DESIGN PERFORMANCE MEASURES

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ABSTRACT

The authors are developing and testing two sets of Universal Design Performance Measures that reflect the Principles of Universal Design. One version is useful for individuals assessing products before purchase and the other version for product designers developing new products. The Measures are currently being pilot tested with 18 designer and 60 consumer households.

BACKGROUND

The authors are conducting a three-year field-initiated project, funded by the National Institute on Disability and Rehabilitation Research (NIDRR), titled "Promoting the Practice of Universal Design." The purpose of the project is to increase the acceptance and adoption of the universal design approach by mainstream product industries. One project task is to develop a method of evaluating products to determine their universal usability; another task is to develop an evaluation service for industry based on this evaluation method; and a third task is to explore the possibility of establishing a recognition or certification program based on the evaluation results. The project began in June 1998, and is scheduled to run through May 2001.

STATEMENT OF THE PROBLEM

This paper presents the results of the first year and a half of project work regarding the development of a set of Universal Design Performance Measures that are based on the Principles of Universal Design (1) (2) and are easier to apply. The Performance Measures are intended to be used by consumers to assess products, either before purchase or already owned, and by product designers to guide the development of more universally usable new products.

RATIONALE

While several pieces of U.S. legislation (e.g., the Fair Housing Act, the Americans with Disabilities Act, Section 255 of the Telecommunications Act) have made some elements of the built environment more accessible to the general public, the majority of everyday products remain substantially unaffected by legislation. However, the design details of such devices can make a significant difference in an individual's ability to live independently and comfortably. To maximize the broad usability of products, industry must be convinced to address the needs of the most diverse possible group of users. Advocates must prove to industry management the worth of the universal design approach and facilitate product designers' application of it.

DESIGN

The authors originally had hoped to develop a single set of Universal Design Performance Measures that could be used by consumers as well as designers so both groups would be literally working off the same page. This, however, proved to be inappropriate. Consumers are concerned only with issues that relate to their personal needs, while designers should address the needs of the widest diversity of users concurrently. Each constituency requires its own document.

For this reason, two versions of the Universal Design Performance Measures, or "Product Evaluation Survey," were developed. The consumer and designer versions of the Survey each comprise a set of 29 statements corresponding to the 29 guidelines in the Principles of Universal Design. The Principles and the two versions of the Survey all address the same issues, but each takes a different approach. As an example, the following table compares Section 2: _Flexibility in Use_ in each of the three documents.

The Principles of Universal Design	Consumers' Product Evaluation Survey	Designers' Product Evaluation Survey
2A.Provide choice in methods of use.	2A.I can use this product in whatever way(s) are safe and effective for me.	2A. The product offers any user at least one way to use it safely and effectively.
2B.Accommodate right- or left-handed access and use.	2B.I can use this product with either my right or left side (hand or foot) alone.	2B. This product can be used by either right- or left-dominant users, including amputees with or without prostheses.
2C.Facilitate the user's accuracy and precision.	2C.I can use this product precisely and accurately.	2C. This product facilitates (or does not require) the user's accuracy and precision.
2D.Provide adaptability to the user's pace.	2D.I can use this product as quickly or as slowly as I want.	2D. This product can be used as quickly or as slowly as the user wants.

Next to each statement in the Product Evaluation Surveys is a set of six boxes: Strongly Agree, Agree, Neither Agree Nor Disagree, Disagree, Strongly Disagree, and Not Important. Participants are asked to circle or "X" their responses to each statement.

DEVELOPMENT

The initial phase of the development process of the Universal Design Performance Measures was described in an earlier paper, published in the proceedings of the RESNA '99 conference (3). Five original draft versions of the Performance Measures were reviewed by 28 consumers with disabilities, 18 professional product designers, and 12 marketing managers from across the United States. These were distilled into draft versions of the two Product Evaluation Surveys described above, one for consumers and one for designers. The two draft Surveys were reviewed by five project advisors and pilot-tested by four colleague advisors, who suggested changes that were incorporated into the documents that are being tested currently.

EVALUATION

Testing of the Product Evaluation Surveys is currently underway with consumer households and professional product designers. Test participants were chosen to be as diverse a group as possible in terms of age, abilities, race, geographic location, and socioeconomic status. In order to assess the true universal usability of the Performance Measures, the consumer group includes 60 households, 36 of which contain at least one member with an identifiable disability and 24 of which contain no one with a disability. The designer group includes 18 households, some containing individuals with disabilities, and representing a range of experience with and attitudes toward universal design.

Each household was sent four common home products. Participants were asked to have everyone in the household use each product, as appropriate, and keep a carefully structured journal documenting everyone's use of and comments about the products. After using the products for a few weeks, the testing participants were asked to complete a set of four Product Evaluation Surveys, one for each product. (The consumer households received the consumer version of the Survey and the designer households received the designer version.)

The results of the pilot tests will be analyzed in two ways.

- First, the responses marked on the Product Evaluation Surveys will be compared with the comments made in the journal of use to assess the extent to which they agree. Project staff will identify any comments made in the journal that were not reflected in the Survey. In cases where the Survey does not fully capture the experiences and feedback of the test participants, the Survey may be modified.
- Second, the responses marked on the Surveys and the comments made in the journal will be aggregated for all test participants to see if they yield useful information regarding the universal usability of the products. Ideally, this methodology will produce a profile of consumer experience with each product that, as part of an evaluation service for industry, would assist its manufacturer to make the product easier to use and more desirable to purchase for a diverse group of users.

DISCUSSION

The authors are concerned that the Product Evaluation Surveys may not address the full range of product use, from opening the package and reading the instructions to using, storing, and discarding the product. Because the journal of use was structured to elicit comments about all these aspects of use, testing results should reveal the severity of the problem and may suggest ways to solve it.

The authors hope that the final Product Evaluation Surveys will be useful for individuals and professionals assessing the adequacy of products. In the proposed product evaluation service for industry, comments made by consumer evaluators in the journals of use would provide rich feedback to manufacturers regarding the broad usability of products. The testing currently underway will help assess whether the scores recorded on the consumer Product Evaluation Surveys would constitute a viable basis for a universal design recognition program.

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MIPHONE: THE MULTIPLE INPUT SPEAKER TELEPHONE

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ABSTRACT

Commercially available voice modems have opened the way for a new cost-effective speakerphone that provides a range of selection methods. The MiPhone provides a range of multiple inputs suitable for the needs of users with a disability. Users can gain direct access to the phone using one to eight switches, scanning access using one to four switches, access via alternative AT compatible keyboards and control via other assistive technologies such as AAC and ECU devices that contain trainable infrared controllers.

BACKGROUND

With the advent of commercially available external voice modems that contain the features of a regular speakerphone, allow for the connection of an external speaker and microphone and are controllable via the RS232 connector, it is now feasible to have a dedicated controller added to provide alternative control interfaces that meet the needs of users with disabilities for a reasonable cost. This solution utilizes the fact that the voice modem has already passed the normal testing and approval process necessary for connection to the phone network. These approval processes vary for different countries making the importing of specialised phones impractical for some countries. Garrett, Earl, Seeger and Collins(1) outlined these difficulties.

The dedicated controller removes the need for a computer and appropriate access software/hardware that would need to be powered on for 24hrs per day. Computers use much more power and are susceptible to crashing, leaving a person without a phone until the computer is running again.

DESIGN

The following design is based upon the terminology and concepts found in chapter 6 of Cook & Hussey, "Assistive Technologies: Principles and Practice" (2). In the case of a telephone, the desired *activity output* is the activation of the standard features of the phone. The simplest phone *selection set* necessary to achieve this output is comprised of the following:

The Digits 0 to 9, *, and #
Send (dial the number)
Answer Incoming Call
Hang Up

In order to make a versatile phone, this selection set was extended to also include:

Re-dial previous number
Retrieve and dial 1 to n pre-stored numbers
Save to pre-stored number
Increase and decrease speaker volume
Increase and decrease microphone volume

The *selection method* depends on the nature of each type of control interface. It was therefore considered necessary to separate the *human/technology interface* from the *processor* that actually performs the phone commands corresponding to the items in the above selection set. So that the final system could be configured to the requirements of the user, it was also necessary to design each human/technology interface with its own set of user options. Figure 1 illustrates the design of the accessible phone.

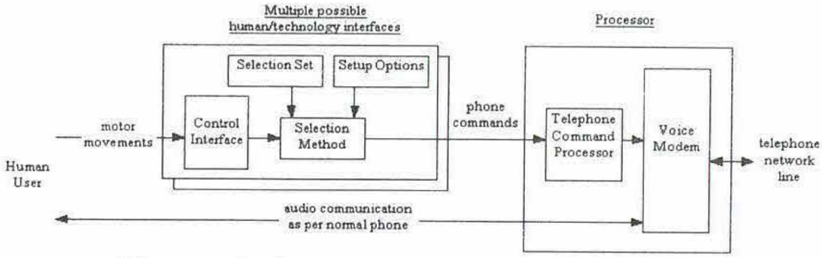

Figure 1: Design of accessible telephone structure

When this design was translated into a prototype product, it was done in such a way that new human/technology interface modules could be developed and then added by simply plugging them into a standardized connector attached to the processor hardware.

DEVELOPMENT

A manufacturing prototype has been developed and named MiPhone™ (Multiple Input Phone). It incorporates a 12 mm (1/2 inch) tall vacuum fluorescent display for high contrast visual feedback. Figure 2 shows the MiPhone™ with the voice modem and several possible control interfaces: an Intellikeys keyboard, a DeltaTalker and four Ablenet switches.

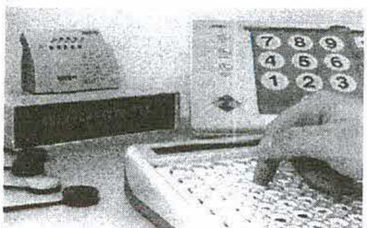

Figure 2. MiPhone™ with the voice modem and some of the possible interfaces.

FEATURES OF THE PHONE

A single phone has been created which can provide for the needs or preferences of many people. It is likely that an individual will choose to use only one of the input facilities. Alternatively, in an environment where multiple different access methods may be required, all access methods may be used in conjunction with each other. These features have been facilitated by a modular design approach.

POTENTIAL USERS AND INPUT REQUIREMENTS

The MiPhone supports switch scanning, direct switch access, multi-switch control, keyboard control and infrared input.

Direct Switch Access

Someone who has cognitive and/or motor impairments may benefit from using the option of direct switch access. Photographs or names may be placed on the switches, and a single switch press may be used to dial the person indicated. The same switch (or any other switch) can be used to hang up the phone at the end of a conversation, or to answer an incoming call. A maximum of 8 separate switches may be used for direct access. The connectors follow the standards normally used on assistive technology.

Switch Scanning / Multi-switch

A person with quadriplegia who has high cognitive skills but impaired physical abilities may use a single switch, or multi-switch input (for example a switch joystick) in either direct or scan mode. The MiPhone supports automatic and stepped scanning, which allows access to the telephone's functions via one to four switches. Options, such as scan rate and switch hold time, may be adjusted to cater for an individual's needs. Six scan sets are provided, allowing basic, intermediate and complete control of the phone.

Keyboard Access

A person who has restricted motor range or resolution may prefer to use an alternative keyboard. The MiPhone is designed to allow control from an IBM AT-compatible keyboard. A few different keyboard 'layouts' are available so a user's individual requirements are better met.

Infrared Access from an AAC Device or ECU

A person who has cerebral palsy and uses a high-level AAC device or environmental control system may be able to best access the MiPhone via infrared transmission. A trainable infrared remote control, which is present in many AAC devices and ECUs, can be taught the control signals for the MiPhone. The user can then use a device that they already feel comfortable with to gain access to the phone.

FUTURE PLANS

An initial batch of units is being made in-house. These units are now available for evaluation and sale. Plans exist to outsource the manufacturing process as the sales volume increases. We are currently interested in reaching a licensing agreement for manufacturing or reselling the units within North America and anticipate a market price of around US$1000.

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DEVELOPMENT OF AN ELECTRONIC ASSISTIVE TECHNOLOGY CATALOGUE FOR FARMERS, RANCHERS, AND AGRICULTURAL WORKERS

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ABSTRACT

The Breaking New Ground (BNG) Resource Center has been developing resources for farmers and ranchers with physical disabilities for over 20 years. This has included two extensive catalogues of appropriate assistive technology that is commercially available, or has been designed and fabricated by individual craftsmen for agricultural workers. Over 2000 hard copies of Volumes I & II of *Agricultural Tools, Equipment, Machinery, & Buildings for Farmers and Ranchers with Physical Disabilities* have been distributed nationwide to consumers and rehabilitation professionals. A third revision of this resource, The Toolbox, is now available in both print and electronic versions to broaden distribution, increase accessibility, and enhance the quality of the contents. This paper will discuss the selection criteria used to select items in The Toolbox, the design process to allow rapid conversion from print to electronic versions, and dissemination plans.

BACKGROUND

For most of the over three million Americans earning their livings in agriculture, the work is not just their livelihood, it is a way of life; a productive and satisfying way of life of which they are very proud. However, agricultural production is hazardous. The USDA National Agricultural Statistics Service estimates that more than 200,000 farmers, ranchers, and other agricultural workers experience lost-work-time injuries and occupational illnesses every year, approximately five percent of which have serious and permanent results. Off-the-farm injuries and health conditions such as heart disease, arthritis, cancer, and aging related disease disable tens of thousands more . The BNG Resource Center estimates that approximately 500,000 persons working in agriculture have physical disabilities that interfere with their ability to perform essential tasks on the farm or ranch(1). The majority of people with disabilities who work or live in agricultural settings want to continue to do so despite their disabilities. All too often, however, they are frustrated in their attempts. Rural isolation, limited personal resources, gaps in rural service delivery systems, and inadequate access to agriculture-oriented assistance are among the obstacles they face.

OBJECTIVE

Since 1991, the AgrAbility Project, now operating in 19 states, has offered education, assistance, and resources to help identify ways to accommodate disabilities, eliminate barriers, and create a favorable climate among rural service providers for agricultural workers with disabilities. One of the initiatives of this effort has been to increase the amount and enhance the quality of resources available to assist individuals desiring to remain actively involved in agricultural production. One of the most popular resources has been the publication *Agricultural Tools, Equipment, Machinery, & Buildings for Farmers and Ranchers with Physical Disabilities*, which has been used as the primary assistive technology resource by many AgrAbility professionals as they serve the farmers in their states(2). This catalogue, now known as The Toolbox, has been updated to include over 350 products and is available in both a printed and electronic format.

DISCUSSION OF METHODS

Format Selection

Due to the three-ring binder format that increases both publication and assembly cost, only 1000 copies of each of the first two versions of the catalogue were produced. Both printings were quickly exhausted, which suggested that a printed version of the document was still needed. In addition, however, it was determined by surveying present users of the resource that an electronic version in CD and Internet formats would be a valuable improvement and increase accessibility. Therefore, a decision was made to develop both formats in parallel tracks. This required a complete change in the layout of the printed version and a transfer of the original text and photos into an electronic database that could be easily printed on a CD and published on the Internet.

The process followed was to first identify the assistive technology that would be included in the catalogue. Then the assistive technology was organized into sections and task groupings representing the primary activities conducted on farms and ranches. Technical descriptions of each item were then written in Microsoft Word 97, and color pictures of the technology were scanned in and enhanced with PhotoShop. After the final editing was completed, the text descriptions and the images were combined into attractive page layouts in PageMaker Pro. PageMaker software was used because of its compatibility with .PDF, which could be transferred to CD's and the Internet.

Selection Criteria

Numerous catalogues, databases, and other resources exist on the availability of assistive technology for persons with disabilities. The unique aspect of The Toolbox is that the scope of the contents was limited to devices, ideas and practices that were applicable to agricultural workplaces and for use by individuals involved in agricultural production activities. It is believed that the information has also had far reaching applications to many other settings where heavy equipment and outdoor activities are involved.

Primary Categories

Two potential methods of organization were considered for organization of The Toolbox. Technology would fall under either the primary category of disability type or work site activity being explored. It was decided to categorize the information by work site activity and identify the type of disability it applied to for each assistive technology solution.

The main purpose for the agricultural work site category being the primary organizational factor was the small amount of overlap of technology between various work site activities. The eight categories defined were Lawn & Garden, Livestock Handling, Materials Handling & Storage, Outdoor Mobility & ATV's, Recreation, Shop & Hand Tools, Tractors & Combines, and Trucks. Nearly all of the equipment used in agricultural production fell in only one of these eight categories, however, most of the assistive technology could possibly serve several different disability types. Overlapping items were referenced in all pertinent categories. Another reason for organizing by the work site categories was to allow agricultural workers to look directly at the category in which they need equipment modified. Should the farmer, for example, require a special gate for his cattle, he would most likely know to look in the Livestock Handling category.

To help agricultural workers or professionals locate disability-specific technology, an indexing system was devised to identify all assistive devices in the catalogue that would serve a given disability. The disability types were listed as functional groups and included Upper Extremities, Lower Extremities, Back, Respiratory, Visual, Hearing, and Strength & Endurance. The cross-reference index was created to list every page in the manual that served each disability. The reader would review the list of items serving a specific disability, and then look those devices up in the appropriate agricultural work site category.

Specialized Task Groups

Within each major agricultural work site category, the assistive technology was organized into groups by the specific task it was designed to accomplish. For example, under the Tractors & Combines category, there were over 15 specific tasks to address, such as braking, hydraulic controls, and hitching. The braking group included all items that assist farmers in operating the brakes of a tractor. Other examples of groups included *small hand tools* in the Lawn & Garden category or *pickup truck bed access* in the Trucks category.

At the top of the first page of each grouping was the task name, followed by a short statement of the need served. The disabilities served by the items in the group were also listed near the top of each page. After the brief need statement, a detailed description of the task being addressed was provided. This description was included to educate professionals unfamiliar with agriculture on the importance and challenges of the tasks. A list of solutions to the challenges was the next point on the group page. The groups consisted of up to ten devices, and each was given its own detailed description of function and fabrication information. These descriptions were accompanied by a picture, which also displayed the concept and function of each item.

The last point on the grouping pages was a list of suppliers, developers, or knowledgeable sources for each item described. The contact information included, where available, the address, phone number, fax number, email address, Internet address, and estimated cost. With the contact information, users should be able to contact the original sources of the equipment for more detailed technical, fabrication, or pricing information.

Dissemination Plans

The initial dissemination plan included the distribution of a print version of The Toolbox to each of the AgrAbility Project sites for a final review of content clarity and accuracy. Feedback from the professional AgrAbility staff will then be incorporated into the catalogue prior to the production of the CD version. Both versions will then be made available to the general public for purchase. A future goal, as resources become available, will be to publish the contents of The Toolbox on the Internet at the National AgrAbility web site, www.agrability.org.

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DEVELOPMENT OF AN ASSESSEMENT PROTOCOL TO DELIVER HOME MODIFICATION SERVICES TO RURAL ELDERLY

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ABSTRACT

An assessment protocol was developed in the first phase of an NIA SBIR grant that will enable rehabilitation engineers and other home modification specialists to facilitate the delivery of home modification services to underserved rural elders. The protocol is designed to provide these specialists with sufficient information about clients' functional abilities as well as their home environments so that appropriate assistive technologies, adaptive hardware, and construction specifications can be prescribed without having to perform on-site assessments themselves. As a result, home modifications services will be able to be delivered to older adults who have, heretofore, not had access to knowledgeable specialists.

BACKGROUND

Modifying one's home through remodeling, installing adaptive hardware, and using assistive technologies is an important intervention strategy (1, 2) to manage chronic health care conditions, maintain or improve functioning, increase independence, ensure safety of frail older adults who experience functional limitations, and minimize the cost of personal care services. These positive impacts have been demonstrated by a growing body of evidence (3-8). As a result, there is increasing recognition among aging service providers and rehabilitation engineers of the viability of home modifications as a strategy to permit older individuals to successfully age in place. However, implementation of modifications on a broad basis has not yet occurred. A major reason for the underutilization of home modifications is the lack of specialists, particularly in rural areas (9) who can assess both functional abilities of older adults and the relevant environmental characteristics of their homes in order to determine housing needs and prescribe appropriate modifications. A second reason is the lack of a comprehensive assessment tool that will enable specialists to diagnose problems and develop home modification solutions (10).

OBJECTIVE

In response to this need, a new assessment protocol for residential environments has been developed and tested that includes comprehensive assessment of both function and environment. The goal is to provide experts who specialize in home modifications with sufficient information about the home environment and housing needs of older individuals for them to prescribe appropriate adaptive devices, design solutions, and construction specifications without having to travel hundreds of miles to perform on-site assessments. The proposed modifications subsequently can be installed or constructed by local rehabilitation engineers, contractors, handymen/women, family members, or friends.

ASSESSMENT PROTOCOL

APPROACH

Existing literature and assessment instruments, particularly those which are currently used by case managers, occupational therapists, rehab engineers, and other providers of aging services were reviewed to identify the range of functional measures that are assessed; attributes of the environment documented; and the variety of activities and tasks that are assessed. Based on this information, a draft protocol that includes a written instrument, photographic documentation, telephone interviews, and televideo technology was developed. A panel of local and national experts in home modifications and assessment protocols participated in a 2-day meeting to review the draft instrument. Following the expert meeting, revisions were made to the written instrument and procedures as needed. The instrument was then pretested in 5 homes in the Chicago area to determine feasibility.

RESULTS

The first phase of this project focused on development of the written part of the protocol with particular emphasis on refining content, simplifying format and procedures, and clarifying item language to facilitate its use. At the end of this phase, an initial version of the written component of the Comprehensive Assessment Survey Protocol for Aging Residents (CASPAR) had been developed. In addition, its feasibility was demonstrated in the field by using the instrument to collect data in five homes. A comparison of the data collected and the home modification solutions that were developed from the data showed that they were substantially equivalent to the data and solutions derived from typical on-site assessments

DISCUSSION

The second phase of the project will include four activities that will extend the usefulness of the protocol. The first involves the development of additional components of the protocol, including innovative follow-up procedures and training materials, that will enable the protocol to realize its full potential. Second, the effectiveness of the protocol will be demonstrated in a large number of cases across the country. The research undertaken will address the following questions: 1) Does the protocol produce the same results as a typical on-site assessment by a home modifications specialist? 2) Are questions in the protocol responded to by different users in the same way? and 3) Are users of the protocol and clients satisfied with the process and the product? Third, resource materials will be developed to accompany home modification recommendations submitted to clients. The resource materials will provide important information to help clients make informed decisions about the most appropriate modifications for them. Finally, a marketing strategy will be planned to ensure the overall success of commercialization in Phase III and the widest possible use of CASPAR, particularly with underserved rural elders.

Together, the three components of CASPAR, (i.e., survey instrument, training materials, and follow-up procedures), the resource materials, and a marketing strategy will significantly expand the capacity of rehabilitation engineers and other home modification experts to provide individualized modifications to underserved rural elders at reasonable costs even when they are unable to perform on-site assessments.

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GENDER-BASED ANTHROPOMETRIC DIFFERENCES OF MANUAL WHEELCHAIR USERS

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ABSTRACT

Anthropometric data of manual wheelchair users (MWU) is scarce. This study collected bilateral upper extremity and body measures of 49 MWU with spinal cord injury (36 males, 13 females, T5 average). Measurements include weight, stature, upper arm length, forearm length and circumferences of the axilla, elbow, wrist and fist. Results show high correlation bilaterally, correlation between stature and linear measure and weight and circumference measures, significant difference between genders in linear and circumference measures, but similar proportions between genders when considering ratios of stature to linear measure and weight to circumference measure. Lastly, a muscularity ratio demonstrates more muscular upper arms in males. The results provide useful observations for both designers of workspaces and manual wheelchairs.

BACKGROUND

Anthropometric data provides the basis upon which engineers and designers determine the relative sizing of man-machine systems. Ergonomic evaluation of manual wheelchairs requires knowledge of the upper extremity dimensions of the MWU. Previous anthropometric studies have been conducted on MWUs. However, much of this data was recorded during the 1950s and 1960s. Owing to the wheelchair revolution of the early 1980s, the applicability of older data to active, current day MWUs is debatable. More recent studies were conducted by Goswami et al (1), Nowak (2) and Das et al (3). Goswami compared Asian Indian men with and without disabilities. Upon comparing upper extremity measures, it was noted that distributions were closely matched. The author notes, however, that many subjects with disability display variance between right and left arms. Nowak studied young Polish men and women involved in vocational rehabilitation training. Males were found to have significantly larger arm spans and overhead reach. Nowak notes that such differences cannot be ignored in the design of workspaces and mobility devices. Das studied the seated MWU. Data is measured relative to the seat pan which is readily applied to workstation design. Statistical difference was found between males and females in 13 of 16 structural dimensions.

METHODS

Upon giving informed consent, 49 adults with SCI (T5 average level) were measured to determine their body weight, upper and forearm lengths and axilla, elbow, wrist and fist circumferences. Stature was self-reported. Body weight was determined using a 2x2 force plate matrix and finding the difference between weight of the subject while seated in their wheelchair and the weight of the wheelchair alone. Length and circumference data was measured as depicted in figure 1.

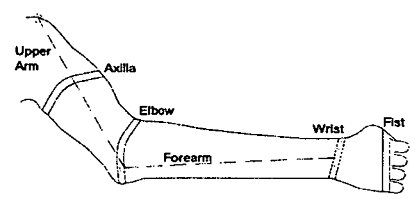

Figure 1: Measurement Protocol

Distributions were calculated for each group (table 1) and comparisons were performed using a Student's t-test with unequal n. From an ergonomic design viewpoint, it is helpful to know if the linear and circumference measures are correlated with stature and weight, respectively. Pearson correlations were computed to determine whether this relationship existed. In addition, design can be aided by knowing if the measures of each gender relative to stature and weight are proportional. To make this comparison, the ratios of stature to linear measures and weight to circumference measures was calculated for each subject. These ratios were analyzed using a Student's t-test with unequal n between genders. Lastly, to compare the relative muscle mass between genders, the ratio of upper arm length to axillary circumference was computed. This ratio was used as the input to a Student's t-test with unequal n. Note that the use of ratios in the last two comparisons eliminates concerns related to statistical error propagation.

Table 1: Distribution Statistics

FEMALE	Mean	SD	Min	Max
Age	34.28	7.67	22.43	45.38
Yrs w/ SCI	12.65	4.90	6.69	23.04
Stature (m)	1.65	0.08	1.55	1.78
Weight (kg)	61.76	17.03	43.09	105.23
BMI	22.56	5.37	17.92	37.45
Circumference*				
Axilla (cm)	31.77	3.96	26.4	43.0
Elbow (cm)	24.55	2.36	21.2	28.5
Wrist (cm)	15.23	1.02	13.0	17.0
Fist (cm)	24.17	1.23	21.0	26.3
Linear*				
Up. Arm (cm)	31.39	3.96	25.4	37.5
Forearm (cm)	25.52	2.15	22.2	28.9

MALE	Mean	SD	Min	Max
Age	38.18	12.27	20.69	68.78
Yrs w/ SCI	11.16	6.96	1.33	29.41
Stature (m)	1.8	0.06	1.71	2.03
Weight (kg)	81.24	14.66	51.71	106.14
BMI	25.15	4.99	14.94	34.56
Circumference*				
Axilla (cm)	38.99	5.21	28.5	52.5
Elbow (cm)	29.40	2.50	24.8	35.3
Wrist (cm)	18.15	1.16	16.5	22.0
Fist (cm)	29.32	1.57	26.2	33.0
Linear*				
Up. Arm (cm)	34.08	3.77	27.5	40.5
Forearm (cm)	28.04	1.76	25.0	31.0

* - Values represent the mean between right and left measurements, [(right + left)/2].

RESULTS

Side-to-side (right, left) comparison of the anthropometric measures shows highly significant correlation (worse case, $r>0.918$, $p<0.01$). Male subjects differed significantly from female subjects in all anthropometric measures via the t-test ($p<0.03$) while there was no significant difference relative to Body Mass Index (BMI, $p=0.124$), age ($p=0.290$ or years post-SCI ($p=0.482$). Pearson correlations were computed to investigate whether a relationship exists between stature and linear measures and weight and circumference measures of all subjects (table 2). Results show axillary and fist circumference to be significantly correlated to weight. Similarly, upper arm and forearm lengths are significantly correlated to stature. Ratios between weight and circumference measures (axilla and fist) and stature and linear measures (upper are and forearm) were computed to determine whether females and males are proportioned differently. An independent samples t-test showed a significant difference *does not* exist between genders; thus, subjects in this study *did not* show different body proportion based on gender (table 3). Comparison of the muscularity of the upper arm was made by computing the ratio of axillary circumference to upper arm length and using an independent samples t-test. This test demonstrated a significantly larger ratio (more muscle) in males than females ($t=-2.20$, $p=0.03$).

Table 2: Pearson Correlations

	r	Sig.
Weight & Axilla	0.67	0.000
Weight & Fist	0.66	0.000
Stature & Up. Arm	0.53	0.000
Stature & Forearm	0.69	0.000

Table 3: Between Gender Body Ratio t-test

	t	Sig.
Weight:Axilla	-1.59	0.12
Weight:Fist	-1.36	0.18
Stature:Upper Arm	-0.28	0.78
Stature:Forearm	0.37	0.71

CONCLUSIONS

This study has considered the upper extremity anthropometrics of female and male manual wheelchair users. Results show a high correlation between right and left arms which contradicts the observation of Goswami for this population. Between gender comparison shows significant difference in all measures, which confirms the observation of Nowak and Das et al. In general, circumference measures correlate to weight and linear measures correlate to stature. In addition, females and males are proportioned similarly with respect to weight and circumference measures and stature and linear measures. Comparison of the muscularity of the upper extremity between gender shows significantly higher muscularity for males.

These results demonstrate differences and similarities that exist in the anthropometrics between genders. Similar gender differences have previously been shown relative to the kinematics of wheelchair propulsion (4). Such results indicate the need for clinicians to consider gender and the resulting anthropometric, muscularity and kinematic differences in prescribing manual wheelchairs. For example, females exhibit less upper arm muscularity and may propel more efficiently if given vinyl-coated pushrims which have been shown to increase the propulsive force transferred to the wheelchair (5). Such clinical applications may allow both men and women to use manual wheelchairs without incurring cumulative injuries.

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Customized Access Ramp Design for Children With Lower Extremity Weakness

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ABSTRACT

Children learn about their environment through exploration, which is most often mediated through motor activity (Kermoian, 7). Children with lower extremity weakness or paralysis often find navigating their environment difficult, and parents or caregivers, wanting their child to be successful, may be inclined to move the child in more expedient ways. While these methods may save time, the child is deprived of learning through exploration and motor activity, and may miss experiencing important changes in the relationship between a person and his/her environment (Kermoian, 7). Depending on caregivers to provide experience also often results in the child adopting learned helplessness behaviors (Case-Smith, 394). Learned helplessness, when not addressed and reversed, is frequently associated with low self-esteem and decreased autonomy later in life (Allen, 180).

BACKGROUND

H.P. is a bright, well-adjusted six-year old male who was born with meningomyelocele spina bifida, which resulted in extreme lower extremity weakness. He is capable of crawling on the floor, pulling himself into and out of the bathtub, and getting into and out of his manual wheelchair. However, other mobility is often difficult for him as he is quite obese. His mother, in the interest of saving time, often picks H.P. up and places him where he wants or needs to be, not only compromising his ability to move himself, but also putting undue strain on her body. H.P.'s occupational therapist indicated that H.P. is not confident of his ability to move his body through space and is exhibiting signs of learned helplessness. It is important to H.P., his mother, and his occupational therapist that he become more confident and independent in his ability to move his body through space successfully. Becoming proficient in accessing furniture such as a couch, his bed, and various chairs in their house was identified as a goal for H.P.

STATEMENT of the PROBLEM

The authors were asked to design a ramp for H.P. that would allow him to access his bed, the couch in the living room, and the dining room chairs. The ramp needed to be mobile so the child could push it from room to room, yet be stable and capable of supporting his weight when he used it to access the furniture.

RATIONALE

Using a mobile ramp to access the furniture in his house, H.P. has an opportunity to increase his confidence in his abilities to move and position himself, increase his endurance, and exercise his motor planning strategies. Using the ramp independently could also be an important step in addressing H.P.'s learned helplessness behaviors.

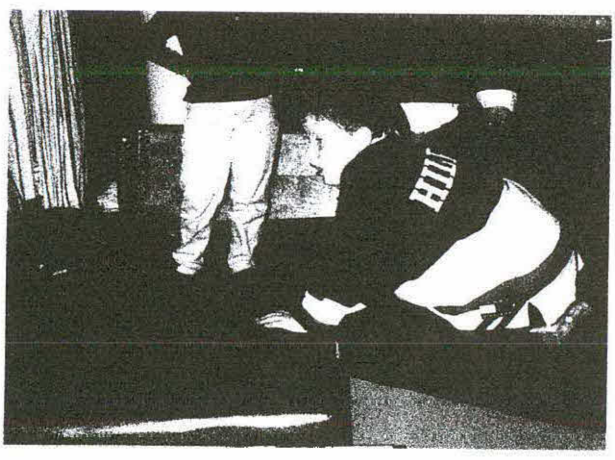
DESIGN and DEVELOPMENT

While seemingly simple, this customized access ramp is quite complex, designed to specifically meet H.P.'s unique capabilities and needs. The initial visit with the child and his mother determined his ability to ascend a variety of inclines, simultaneously considering his level of exertion and height of the furniture to be accessed. A 12" x 24" x 28" incline gave H.P. a just-right challenge; he had to work to access selected furniture, but it was not impossible for him to achieve. It also became apparent that the child required a non-skid surface to climb on, as his motor control is not adequate to hold his lower extremities statically in ascent.

The ramp was constructed of high-density ½" plywood, the edges routed and sanded for safety. The surface of the ramp extended beyond the walls of the ramp one inch per side to give the user a handhold and leverage. Four 4x740 spring-loaded castors were used to provide the ramp mobility when not supporting weight and stability when H.P. compressed the springs during use. The castors could not be used as purchased and had to be modified. The two castors used at the base of the ramp proved to be too big to allow the frame to rest on the floor during compression, so the castor bracket was disassembled and the shaft was cut and re-threaded. The housing system (a C-bracket) was now too large for the castor, so a new C-bracket was fabricated with two pieces of beveled angle iron. The springs on all four castors were replaced as the original springs were too stiff for H.P. to compress independently. The short castors were then attached to a mounting block, which then was directly attached to the frame of the ramp. The tall castors mounted directly to the frame. Additionally, a shim was installed between each mounting block and the frame of the ramp to provide more clearance for the castor wheel when rolling. These modifications resulted in a medium weight, smooth rolling ramp that was extremely stable upon compression. Quarter-inch high-density PVC foam was glued to the surface of the ramp to provide some traction and cushioning for H.P.'s knees. The body of the ramp was painted teal per H.P.'s request, and finally, a denim cover with heavy-duty non-skid shelf liner pads sewn into it was fabricated for aesthetic appearance and increased traction as H.P. ascended the ramp. The cover was secured to the ramp with sturdy Velcro so it could be removed for cleaning.

EVALUATION

H.P. and his mother were both initially delighted with the access ramp. In a follow-up interview, the child's mother reported, "He uses it all the time! He lies on it, sits on it, pushes it around the living room floor, and climbs on it, every day!" H.P. thought the ramp was "cool."



DISCUSSION

Children best develop self-determined behavior when they learn across multiple environments and within multiple domains (Doll, 65). It is important to empower children in ways that will allow them to explore and master their environment, whether it be through high tech or low-tech devices. This becomes especially important if a child has a disability and is limited by decreased opportunity for movement and play. This limited opportunity to practice behaviors important for the development of self-determination at a young age may constrain expression of self-determination later in life (Doll, 68). Supporting the child with a disability in the exploration of their environment fosters growth, decreases behaviors associated with learned helplessness, encourages autonomy, and provides a sense of accomplishment and mastery that may otherwise be absent (Ellsworth, 23).

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WORKSITE MODIFICATION AND LIFESTYLE REDESIGN: A QUICK FIX

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ABSTRACT

Worksite modification and lifestyle redesign were utilized to provide a quick fix for a person with musculoskeletal disorder (MSD) signs and symptoms during computer-based tasks. The case study's participant reported her work-related performance had declined recently because of back and neck pain, stiffness, fatigue, and dizziness. Worksite modification included materially reducing MSD hazards in the participant's existing workstation and recommending the purchase of an adjustable footstool. For the participant, lifestyle redesign included increasing her body awareness and providing strategies to improve her work performance. Following this quick fix, the participant returned to improved work function with increased endurance and without pain, stiffness, fatigue, or dizziness.

BACKGROUND

According to Occupational Safety and Health Administration (OSHA), 1.8 million workers annually experience MSDs related to repetitive motion (1). With the intent of providing workers with ergonomic protection, OSHA proposed an ergonomics standard designed to prevent these injuries. In addition to providing guidelines for developing and implementing basic and full ergonomics programs, OSHA's proposed standard offers the quick fix, a one time option of eliminating MSD hazards and providing controls to fit a job to a worker with a covered MSD, thus fixing the problem job quickly and completely (1).

Although aimed primarily at workers involved in manual handling or manufacturing production jobs, the proposed OSHA standard also protects general industry employees including office workers. Office furniture is a common site of MSD hazards for persons whose jobs have computer work as a core element. Kroemer (2) advocates viewing workstation furniture components as parts of an interactive system in which visual targets, manipulation areas, and body support interact to affect the postures and habits of the office worker (p. 229). In addition to reducing or eliminating ergonomic risk factors in the workplace, habit patterns of workers may require modification. To promote healthy interaction with the environment, the lifestyle redesign approach can successfully change habit patterns (3).

OBJECTIVE

The objective of this case study was to utilize worksite modification and lifestyle redesign to provide a quick fix for the participant during computer-based tasks. The participant was a tall, slender, middle-aged female who works as an information manager and spends between 30 and 50 percent of her job at her computer workstation. Complaining of fatigue, dizziness, and MSD symptoms that included neck pain, back pain, and stiffness, she reported her work-related performance had declined recently because she was unable to spend more than 30 minutes using her computer.

APPROACH

To determine the need for worksite modification and lifestyle redesign, evaluation consisted of multiple measures including interview and skilled observation of the participant at her computer. The participant was assessed for MSD signs and performance component status; concomitantly, her worksite and job were evaluated for ergonomic risk factors.

RESULTS

For the participant, Table 1 delineates findings prior to the ergonomic quick fix and outcomes resulting from worksite modification and lifestyle redesign. Related to environmental factors, key findings were (a) a new 18 inch monitor (recently upgraded from a 12 inch screen), located on top of the processor box at the front edge of the desk; (b) an adjustable under-the-desk mounted keyboard drawer with a mousepad extension; and (c) an expensive ergonomic office chair that had never been adjusted.

Table 1: MSD Symptoms and Other Complaints Pre and Post Quick Fix

Complaints	Pre Quick Fix	Post Quick Fix
Stiffness	On-going	None
Back pain	Internal trunk stability	External trunk support
Neck pain	Hyperextension	Neutral
Fatigue	On-going	None
Dizziness	On-going	None

Key findings in the participant's performance components included (a) movement of the head from side to side to view the screen (due to new, fashionable, single-vision eye glasses with small lenses that replaced out-of-date larger lenses), (b) neck hyperextension to view the monitor, and (c) postural stability located internally because of her natural seated position of sitting with a straight back in the chair, three inches away from contact with the chair back. Her internal stability pattern, which consisted of holding muscle tone bilaterally in her rotator cuff musculature, contributed to the MSD sign of decreased range of motion (ROM); specifically, she lacked 90 degrees in active shoulder abduction and extension bilaterally. The participant exhibited the MSD sign, loss of function, due to the presence of MSD risk factions that included repetition, awkward posture, and static posture.

The quick fix controls, which consisted of worksite modifications and lifestyle redesign, primarily addressed the participant's MSD symptoms (neck pain, back pain, and stiffness) and complaints (fatigue and dizziness). First, the ergonomic chair was adjusted to decrease the participant's back pain and stiffness, and increase her endurance by changing her preferred mode of trunk stability from internal to external. To provide appropriate external stability for the participant, the chair's arms were moved medially, the height was adjusted pneumatically, the back was moved forward to provide support, and the tilt-in-space aspect was demonstrated to show alternative body position options. Books stacked underneath the participant's shoes provided adequate support for her feet, which were not supported at all when the height of the chair was changed. Next, the monitor was lowered from the processor box to the desk surface. This new monitor position allowed the participant's head to remain in a neutral position, thus decreasing neck hyperextension which contributed to her neck pain, stiffness, and fatigue because of the energy she expended working against gravity. To decrease the sideways head movements that contributed to the participant's dizziness, the space between the participant and the screen was increased by moving the monitor to the furthest edge of the desk and pulling out the keyboard drawer to the maximum point away from the desk and toward the participant. By repositioning the monitor, the participant no longer needed to move her head to each side to see the entire screen. (If her sideways head movements had not been eliminated, the next step would have been to return to her smaller monitor.) After adjusting the existing workstation, just one purchase was recommended—an adjustable footstool to allow for the participant's various shoe heel heights.

For the participant, lifestyle redesign involved increasing her body awareness and providing strategies to improve her work performance. Increasing body awareness allowed the participant to guard against tightness in her rotator cuff musculature, sideways movements of her head, and neck hyperextension. Although the participant had not complained of wrist pain, she also learned preventive measures that included monitoring her wrists for appropriate position at the computer keyboard. Four strategies helped the participant improve her work performance. The first strategy permitted her to continue using internal stability by modifying this habit pattern to allow for more healthy utilization. She learned to use a secondary stability strategy of keeping her arms along the sides of her body and relaxing her rotator cuff musculature, using gravity to keep her elbows on the arms of her chair. To provide a habit pattern of making daily chair adjustments, the participant learned a third strategy of leaving her workstation with her pneumatic chair at the highest level when departing at lunchtime or for the evening. The fourth strategy was incorporating frequent rest and stretch breaks into her work routine.

DISCUSSION

For persons who use computers as work tools, neck pain, back pain, and stiffness are frequent MSD symptoms, which often necessitate materially reducing MSD hazards. Although dizziness is a common complaint, particularly with the popularity of eyeglasses having multiple use lenses (e.g., bifocals or trifocals), head movement is more often up-and-down rather than side-to-side as in this case. Recent changes in two visual surface areas played a key role in the dizziness of this participant. Not only did her new, more fashionable eyeglasses with smaller lenses provide her with less surface area having visual correction, she also moved to the larger surface area of a bigger monitor. To cope with the dual visual surface area changes, the participant adapted by moving her head to each side.

A proponent of the tenet that many postures may be comfortable (healthy, suitable, efficient, etc.) depending on a person's body, preferences, and work activities, Kroemer maintains that furniture should allow many postural variations and permit easy adjustment (2, p. 225). To provide many postures, a combination of worksite modification and lifestyle redesign principles provided a quick fix. Although OSHA estimated annual modifications of a single workstation to cost $150 under the proposed ergonomic standard (1), the expense of an adjustable footstool for the participant is well under this price. This ergonomic quick fix resulted in secondary gains in addition to improving work function. With active shoulder ROM within the functional range, the participant engaged more fully in other everyday tasks: she returned to wearing pullover sweaters and took part in tai chi classes.

Inherent in single system designs, the primary limitation of this case study is participation of one subject. This study has strong internal validity for this participant: the results showed the quick fix controls, which consisted of worksite modifications and lifestyle redesign, had positive outcomes for her. The external validity of any single system design is weak, making generalization to a wider group of people difficult; however, case studies that replicate an approach and attain similar results can provide a useful method of accumulating information regarding quick fix controls that work.

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THE ELECTRONIC TALKING LABEL (E-LABEL)

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ABSTRACT

There are approximately fifteen million people who are blind or visually impaired in the United States. Legally blind includes having a central visual acuity of 20/2000 or poorer, or a field of vision no greater than 20 degrees. Products such Magnetic Strip Recorder and Scotch™ (Braille) Labeler were developed in an attempt to help the blind, but they are costly or require a person to be Braille literate. The E-Label, on the other hand, is inexpensive and accommodates virtually every single blind person, Braille literate or not, because it records a person's own voice for labeling. This is essential for independent living, and very crucial when it comes to labeling medication.

BACKGROUND

Every eleven minutes a person loses their eyesight to age-related macular degeneration, glaucoma, diabetic retinopathy, or cataracts amongst other causes (1). These people make up sixty-eight percent of the fifteen million Americans who are blind or partially sighted (2). The Braille Institute defines legally blind individuals have a central visual acuity of 20/2000 or less in the better eye or when their field of peripheral vision is 20 degrees or less (3). Furthermore, those who cannot read the largest letter on the eye chart even with corrected lenses are also considered legally blind (3). Such visual impairments create obstacles for the individual to perform independent living skills such as eating, dressing, identifying objects, and personal hygiene.

In an effort to help the blind with identifying household items, 3M oversaw the development of the Scotch™ (Braille) Labeler (4). This device manually produces a Braille script by turning the alphabet wheel to the specified letter and then clicking the trigger. The resulting script is embossed on a plastic strip that can be attached to the item of choice by exposing the adhesive glue on the back of the strip. This Braille Labeler is often used in conjunction with a medicine storage box to separate and label different kinds of medication. Medicine is placed into different compartments and each compartment is labeled with the essential information. Many blind individuals simply opt to wrap a rubber band around their medicine bottles and use multiple rubber bands to signify the frequency of daily dosage (5). The Magnetic Strip Recorder, developed by Ann Morris Enterprises Inc., is a 10"x7" device that records less than ten seconds of a message and stores it on the magnetic strip affixed to the 10"x3" card (6). The card plays the message when it is inserted back into the unit.

The main flaw associated with these devices is their lack of universal design. The Braille Labeler is only useful to the 10% of the blind individuals who are Braille literate (1). This is because many individuals find learning Braille difficult or are forced to stop reading Braille due to loss of sensation in their fingertips as a result of diabetes. The medicine box and use of rubber bands are also ineffective since they do not distinguish between the different types of medicine without using the Braille Labeler. The Magnetic Strip cards have large dimensions that can only label large items. In addition, a person has to use a rubber band and wrap the card around the object in order to label it. This could make it very inconvenient and much of a hassle if the card falls off or lost. For a device that has limited use, the Magnetic Strip Recorder costs around $80.

STATEMENT OF PROBLEM

The objective of this design is to improve the lives of individuals who are blind or partially sighted by designing an assistive technology device that will seek to increase their level of independence. The E-LABEL, or Electronic Talking Label, is a small, attachable recording device in which an individual can use to label large and small items that cannot be distinguished by touch. Such items could be orange juice or milk cartons, generic containers that store different kinds of food, and medication bottles/containers to provide information about daily dosage consumption, and whether it is to be taken with food or not.

DESIGN APPROACH

The Electronic Talking Label consists of a recordable unit (including a microchip, microphone, and speaker), four batteries, a Velcro strip, and a pressure sensor as optional (Figure 1). The price of a pressure sensor is $8.00 and is an add-on option for individuals who have difficulty pressing small buttons or no sensation in their fingertips. A person who chooses this option places the pressure sensor connected to the device via Velcro next to the device on an object or around it. Upon detecting pressure applied to it, such as a hand gripping on an object, the pressure sensor triggers the device to play the recorded message. The recordable device used for the prototype costs $14.95 from Radio Shack, although similar, but smaller in size, recording devices found in holiday/birthday cards and jewelry cases cost between $1.00-$3.00 and require one battery to operate. It consists of a re-recordable microchip that digitally stores any audio up to ten seconds. It not only plays back a person's own voice, but also another recognizable voice (if someone else records their voice) rather than synthesized recordings. Its operating temperatures are 32°F to 104°F (0°C to 40°C) (7). This means that the device, when attached by a Velcro on an object, can be store in places such as the refrigerator for food and medication, or in other ambient locations. The prototype uses four button cell type 76 batteries that lasts approximately a year with reasonable use (6x per day) and costs less than $2 to replace. The Velcro used to attach the Electronic Talking Label to the intended object will cost less than 25 cents for each label. Labor costs will be incurred for assembly but this should not require extensive time. The entire assembled device will roughly be priced in the range of $3.25-$5.25 without the pressure sensor and weighs approximately one ounce (less than 2 oz. for the prototype).

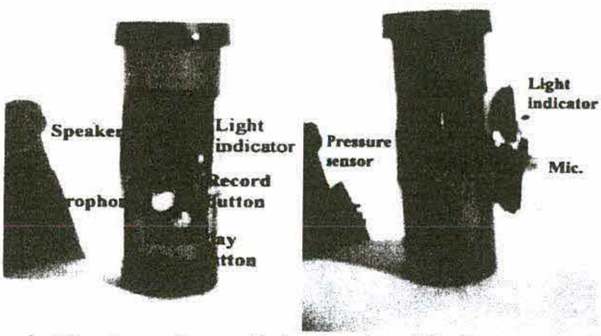

Figure 1: The front and side view of a medicine bottle with the attached E-Label and Velcro.

DISCUSSION

The Electronic Talking Label is designed to assist individuals whom include a large portion of the ninety percent who are blind and Braille illiterate. The onset of blindness affects the elderly rather prevalently. Many of these individuals do not learn Braille, thus they cannot use Braille labeler. The Scotch Braille labeler is a six-year old, low-tech assistive technology device used to label items with a plastic strip embossed with Braille. Therefore, many of the problems aforementioned make their lives even more difficult because they must learn Braille and then learn how to use the device. The cards for the Magnetic Strip Recorder can only label large items and can easily be misplaced or fall off because they are held in place to the object by rubber bands. With our design, the Electronic Talking Labels, activities of daily living should be made more simple and livable: just press the button, say what needs to be labeled, affix the object to the device via adhesive Velcro to the item, and it is ready for storage. The only requirement is that the individual must not be deaf. Some of the tangible benefits that our design may have include no longer needing to store a carton of milk on one side of the refrigerator and their orange juice on the other, someone to and no longer separating medication into a medicine storage box in which medicine are placed in different compartments separated according to frequency of intake. In essence, it enhances self-care, and furthers independence, self-esteem. The Electronic Talking Label is universal in design because it can be use by both the Braille literate and illiterate populations. It could also benefit able-bodied individuals as well, who have difficulty reading small prints. A device this small, inexpensive, and functional has the potential to improve the quality of life of many individuals with blindness.

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ROTATING SHELF 2000:
A REMOTE CONTROLLED AUTOMATED SHELF/STORAGE SYSTEM

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ABSTRACT

Many individuals find it difficult to reach for objects in their homes, such as items on shelves and in their bathroom cabinets. The rotating shelf design is intended to limit this difficulty. The idea was inspired by the rotating vending machines, Lazy Susan cabinets and turntables. The major function of the rotating shelf design is to bring objects within reaching distance for the disabled user. The design creates a mobile space that brings objects within reach to the users. The rotating shelf contains a base support that houses the motor that would rotate a round platform that contains the ball bearing mechanism. It is lightweight, space saving, stackable, easy to assemble and inexpensive.

BACKGROUND

As present, there are no existing compact and remote operated devices that are used for the same applications and focus on the same user groups as that of the "Rotating Shelf 2000." The design of the rotating shelf is inspired by various devices such as the microwave that offers its small, rotating feature, while the vending machine adds its compartmentalization and stacking ability. The Lazy Susan contributes its ball-bearing mechanism to facilitate a smoother, more energy-efficient rotation, while the Chinese dining table adds its versatility and universality of use. One existing device that is commercially available is the "Lift Shelf Storage Retrieval System" (1). This device is a large cabinet-like system with elevating shelves adjustable to the user's preferred height and workspace. However, besides the size, expense, and labor, the major drawback of this system is that there are no lateral, in-plane mobile shelves available. Thus, the user is still required to be mobile in the horizontal plane. Our design takes advantage of the idea that objects would smoothly rotate close to the user's access, while being lightweight, easy to assemble and affordable.

Rotating Shelf 2000 is designed to be as beneficial to as many users with disability as possible in their activities of daily living. However, the focus of the design is mainly to aid those who have difficulty standing and thus use a wheelchair or who mostly sit in a chair while at home. These could include individuals with significant problems of reaching, due to spinal cord injury, osteoarthritis (2), musculoskeletal weakness, joint contracture, and lack of energy (3). Thus, the target user groups of the "Rotating Shelf 2000" are those who have a limited range of motion and thus have trouble bending and reaching forward or above, especially in the upper limbs and thoracic region. In addition, the shelf will maximize space and improve organization of items, while minimizing energy and time management of the user. For example, one of the many daily activities that can be improved by the motorized shelf is to have several appliances assembled on top of the platform. Then by simply rotating the table until the desired appliance is directly in front of the user, he/she is able to remain in the same position without having to move to a different area of the room to reach a different appliance. Another display of the potential of this design is to move food items usually stored toward the deep end of the cabinet or refrigerator onto the platform. This will allow the user to have easy access to all objects in their cabinet rather than having to only utilize items stored on the edge of the shelf.

There are specific examples of where and how the "Rotating Shelf 2000" can be utilized—many of the ideas come directly from the potential users in addition to those suggested by the design team. For example, the shelf can be placed in the refrigerator to maximize space and provide easy access for food. The design can also be utilized in the closet to organize various objects, such as shoes. The rotating shelf can be useful in an office setting too, in which the user is able to file important documents, books, phones, pen/pencils, and other objects that are readily needed as handy references. The garage can also be organized with this device. The user is able to place tools, bottles, and cleaning solutions that may be needed often. This is also applicable in the bathroom, where appliances and toiletries can be placed for easy access.

DESIGN GOALS

Our goals were to build a motorized, rotating platform that could be both switch and remote controlled Our design approach contained three basic components: a platform, a motor, and a housing unit. The supporting box would house the motor, where the platform was to be placed above the supporting box. Our task was to search for an optimal motor that would be strong, durable enough to support the weight imposed by the platform above, and also generate enough torque at the right speed to rotate the platform.

DESIGN METHOD

A 68-cm diameter composite wood platform ($7.00 in cost) was selected as the tabletop. The motor used in this design was a class B construction type with the following characteristics: 230 V, 50 Hz, 31 RPM ($10 in retail cost). The motor shaft was attached to the platform through fitted gear. A Lazy Susan mechanism ($7.68 in cost) was used as the ball bearing mechanism to provide smooth rotating motion. The motor was housed in a wooden box of dimensions 22cm x 22cm x 16cm. Figure 1 is an assembly drawing of the Rotating Shelf 2000 design. Label 1 refers to the platform, label 2 refers to the ball bearing mechanism, label 3 is an added support wooden disc, label 4 is the motor and label 5 is the supporting box. The motor is connected to a 200 VDC capacitor. One end of an AC power chord ($1 in cost) is connected to the motor while the other end of the AC power outlet chord is connected to the capacitor. The AC power chord provides the power for the system. An added remote control system ($30 in cost) was used for our remote control purposes. The entire system costs amount to $58.18.

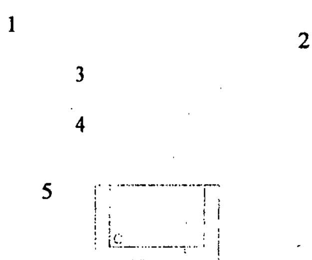

Figure1: Assembly Drawing

RESULTS

The finished prototype is a well functioning unit: it rotates at a fixed speed and can be operated through the remote control system. The total weight of the system is 8 kg and it is capable of supporting up to 14 kg of load. It can be assembled easily and packaged into a box. Figure 2, 3 and 4 are pictures of our finished prototype.

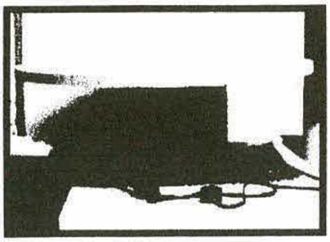

Figure 2: Finished Prototype

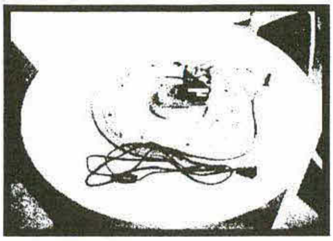

Figure 3: Inner View of the Prototype

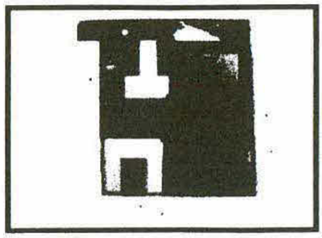

Figure 4: Top View of Supporting Box

DISCUSSION

The rotating shelf is capable of bringing objects placed on top of the platform to reaching distance of the user. Therefore, users with disabilities can live a more independent life. The total cost of our prototype was $58. According to our survey of the target user group, an affordable rage up to $600 was indicated. Since the remote control system alone costs $30, we decided to make this function optional. Thus the system price is based on $28 for the switch operated system. The rotating shelf therefore is functional and affordable.

There are other simple improvements and accessories that are desired to be included in the future design. A rough surface mat was intended to attach onto the top surface of the platform to avoid problems of objects sliding on the tabletop. A plastic cover could be added to help the objects stay clean. A remote control with larger buttons could be useful for users with tremor and vision problems. The platform could also be tailored to hold electric devices. This involves having a central power source in the center of the platform to provide power sources for electronic appliances. For example, the user can place a hair dryer, electric shaver, and electric toothbrush all on the same platform. We also envision a stackable design that involves strategically placing a vertical pole into the lower platform and placing additional platforms on top of the pole with a locking mechanism to secure the platform.

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BIOPOTENTIAL-BASED ENVIRONMENTAL CONTROL SYSTEM

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ABSTRACT

A biopotential-based environmental control system has been developed to assist the severely disabled. The input to the system is provided by the bioelectric potentials caused by the user's intentional thought, eye, or muscle movement. The device features a variable gain and band-pass to obtain the optimal signal from the user's optimal ability.

BACKGROUND

Some systems in the body, including the brain, the eyes, and the muscles, generate bioelectric potentials. The measurement of brain activity is called an electroencephalogram (EEG). The EEG is composed of 4 frequency ranges, or states – alpha, beta, delta, and theta. The electrooculogram (EOG) is the measure of the potential caused by the movement of the eyes, like looking up, looking down, looking left, looking right. The bioelectric potential associated with muscle movement is called an electromyogram (EMG). An example of a muscle movement in the face is a jaw clench. The signal amplitude and frequency range of each potential is shown in Table 1.

Bioelectric potentials are actually ionic voltages. Electrodes are capable of converting ionic voltages into useful electrical voltages that can turn on, for instance, a light, a television, or a stereo. The ionic voltages must be in the vicinity of the electrodes to accomplish this. If the electrodes are on the forehead, EEGs, EOGs, and EMGs may all be transformed into a useful signal.

Table1. Reference ranges for the amplitude and frequency of EEG, EOG, and EMG signals

SIGNAL	STATE	AMPLITUDE (μV)	FREQUENCY (Hz)
Electroencephalogram (EEG)	Alpha	20 - 60	8 – 13
	Beta	2 – 20	14 - 30
	Delta	20 - 200	0.5 – 3.5
	Theta	20 - 100	4 - 7
Electrooculogram (EOG)		50 - 3500	DC - 50
Electromyogram (EMG)		20 - 200	0.2 - 30

STATEMENT OF THE PROBLEM

People with severe disabilities, unable to move their limbs or speak, could use their bioelectric potentials to control their environment. Each person has his or her own individual abilities. Someone with amyotrophic lateral sclerosis may only be able to move their eyes, while someone who has had a paralyzing stroke can only clench their jaw. A third person may be so incapacitated they have control only of their thoughts. An environmental control system that can be adjusted to produce a reliable output when the input is variable is needed.

DESIGN DEVELOPMENT

A system that uses bioelectric potentials as the input and has a variable gain and band-pass meets this need. This biopotential-based system works as follows. The user applies a small amount of conductive hydro-gel to the electrodes that will improve the electrode connection to the forehead. The electrodes, which are sewn into a headband for convenience, are placed on the user's forehead. The user intentionally makes their best move (eye, muscle, thought) causing a bioelectric potential (EOG, EMG, EEG). The electrodes provide an electric signal, proportional to the bioelectric potential, to an instrumentation amplifier. The amplifier has a potentiometer that may be adjusted to obtain a variable gain of the signal. The signal then goes through a filter to remove unwanted signals. The filter is designed to allow a variable band-pass. Next, a DC restorer will clamp the lowest peak of the signal waveform to zero volts to provide a good DC component. A comparator then converts the analog signal into a digital signal. The digital signal triggers a switch that controls an environmental control unit through sequencing logic.

Displays placed after the amplifier and the filter show the voltage level at those points. These displays aid in training the user as well as indicate when adjustments are necessary. The voltage value that is required to operate the switch will be marked on the displays. If the required voltage level is not being met, the gain and/or band-pass may be adjusted using the appropriate dial. A picture of the unit, including the electrode headband and power supply, is shown in Figure 2.

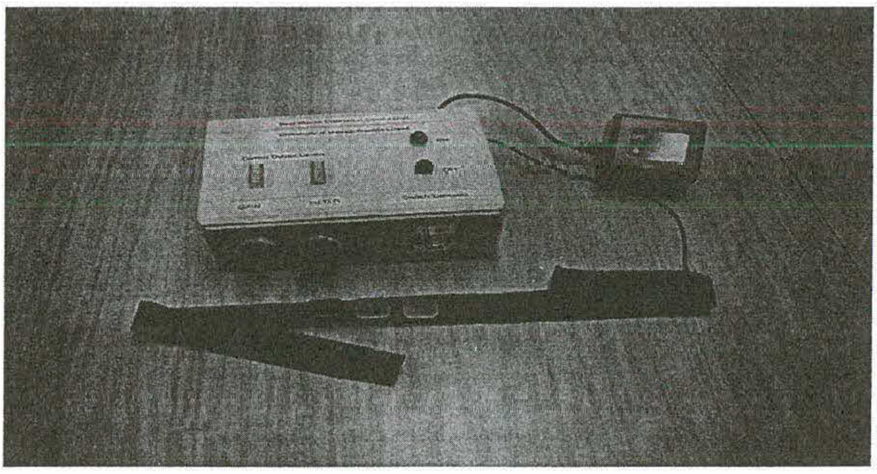

Figure 2. Biopotential-Based Control Unit with Adjustable Gain and Band-Pass

DISCUSSION

A biopotential based environmental control system allows the severely disabled to have a degree of independence. The tunable gain and band-pass feature permits the system to be adjusted to an individual's abilities. It will serve a greater population in this way. Also, if the individual has a progressive disease, like amyotrophic lateral sclerosis, they could continue to use this system by adjusting the sensitivity of the amplifier and the band-pass filter.

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CASE STUDY: USE OF SELF-ELEVATING VEHICLES WITHIN WAREHOUSE OPERATIONS

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ABSTRACT

Within automotive parts distribution centers and warehouses, racks and bins range in height from floor level to approximately 140 inches to store parts. Traditionally, workers have used ladder carts or powered ladder trucks to stock and pick parts. Use of these vehicles involves manual activities such as pushing and climbing ladders to reach high bins. An intervention trial was conducted in which self-elevating vehicles were introduced. The self-elevating vehicle allowed powered movement, both horizontally and vertically. During the intervention trial, systematic evaluations of work posture, work activities and worker assessments were completed. Use of the self-elevating vehicle improved shoulder posture and eliminated climbing ladders and pushing carts. Workers felt that the self-elevating vehicle reduced the physical stress associated with their job.

BACKGROUND

This intervention study was conducted within the replacement parts division of a large automobile manufacturer. Distribution centers were organized in a two-tier system. Regional centers filled orders for replacement parts from the service departments of retail car dealers. National centers obtained replacement parts in bulk and replenished the regional centers as needed. Review of injury records covering a three-year period revealed that overexertion injuries were common due to manual materials handling activities and manual packing tasks. Ergonomic evaluations were performed to measure ergonomic stresses for selected work activities suggested by the injury analysis. In addition, ergonomics professionals walked through the facilities to understand the ergonomic challenges, and joint labor-management committees from each of the distribution centers identified their top 10 ergonomic concerns. These three sources of information were combined to identify opportunities for ergonomic intervention.

Traditionally, workers within the distribution centers have stocked and picked parts from racks and bins that range in height from floor level to approximately 140 inches. The vehicles used for transporting parts around the warehouse and for reaching the high bin locations have generally been ladder carts or powered ladder trucks. The primary ergonomic concerns when stocking and picking using the ladder cart or powered ladder truck included (see Figure 1):

1) pushing the ladder cart to the various rack locations,
2) shoulder elevation and extended reaches into the bins to reduce the actual number of steps climbed on the ladder, and
3) climbing up and down on the equipment (50% of the time workers have objects in their hand while climbing) (see Figure 1).

This was also a safety concern of increased risk of falling when climbing with only one hand on the ladder railing.

One intervention that was identified was a self-elevating vehicle. This is a battery powered vehicle that travels horizontally at a speed of 4.0 mph and can raise the worker to a vertical height of 161 inches (see Figure 2).

Figure 1: Workers must climb up and down the ladder with boxes or parts in one hand (powered ladder truck shown here).

Figure 2: Elevated vertical position of the self-elevating vehicle (used for stocking and picking).

METHODS

Three ergonomic analysis methods were used to evaluate this intervention: 1) posture analysis of the trunk and shoulders, 2) activity analysis and 3) worker interviews. Each of these methods was used to evaluate this job both pre- and post-intervention.

Posture analysis. A computerized posture analysis system was used to measure the amount of time that awkward postures were observed (1). Awkward posture was defined as a significant deviation from the neutral position of a joint. The analyst classified work postures using special computer software while viewing videotapes of work tasks. Torso and shoulder postures were classified using the posture analysis system. Torso posture was classified into 4 categories: 1) neutral, 2) mild flexion (20-45° forward bending), 3) severe flexion (>45° forward bending), and 4) twisted/bent (more than 20° of axial twisting or lateral bending). Shoulder posture was classified into 3 categories: 1) neutral, 2) mild elevation (45-90° angle between upper arm and torso) and 3) severe elevation (>90° angle between upper arm and torso). Various work tasks were videotaped at the work site and were used for these analyses.

Activity analysis. A computerized activity analysis system was used to quantify the amount of time that workers spent performing various work tasks. Work tasks identified for this activity analysis included: standing on the floor, walking, pushing a vehicle, climbing, working from an elevated position, and standing or driving a vehicle.

Worker interview. The worker interview collected demographic information from the participant and then focused on the specific physical demands of the job he / she regularly performed. During the interview workers were asked to assess their perception of the physical job attributes, the most physically-demanding work tasks, seasonal variations in physical stress, and body discomfort.

RESULTS

Torso Posture. The self-elevating vehicle was not expected to improve trunk posture since workers must still periodically reach to the low bin levels. However, small improvements were observed. Predominantly neutral torso postures were observed when using all equipment. Severe torso flexion (forward bending) was observed in all cases when workers picked or stocked parts from the lower shelves and this was not affected by the introduction of the self-elevating vehicle.

Severe torso flexion was also observed when workers positioned pick order documents on the sides of the powered ladder truck or ladder cart, and this was eliminated with the self-elevating vehicle.

Shoulder Posture. When using the ladder cart or powered ladder truck, non-neutral postures were observed 22.4% of the time. Non-neutral postures occurred when the arms were extended forward and when the shoulder was raised to pick or place objects in bins or to scan bar codes at bin locations. The self-elevating vehicle raises workers vertically to the appropriate bin location for picking or stocking parts. Overall, the self-elevating vehicle reduced the amount of time the shoulder was in non-neutral postures to 12% of the time, roughly one-half of the duration of non-neutral postures with the ladder cart and powered ladder truck. Elevated arms were observed while loading the self-elevating vehicle; both while reaching to the back of the cart to retrieve items (not affected by the intervention) and when stacking items on the self-elevating vehicle.

Activity Analysis. Workers are at increased risk of experiencing a "fall from elevation" accident when climbing, descending, or standing on ladders. The risk of a fall may increase if the worker cannot use both hands to grasp the ladder rails. An analysis of work activities showed that during stocking and picking operations with the ladder cart and powered ladder truck, workers spent approximately one-third of the time working on ladders. This was reduced to zero with the self-elevating vehicle. When using the ladder cart for stocking and picking, workers spent six percent of the time pushing the ladder cart. This was reduced to zero with the self-elevating vehicle.

Worker Interviews. The following findings are based on interviews with three workers who used the powered ladder truck or ladder cart and five workers who used the self-elevating vehicle.

- Workers identified climbing up and down ladders and picking from the lowest shelves as the most physically demanding part of their job.
- There was a modestly significant decrease ($p<0.10$) in worker evaluations of torso postural strain when using the self-elevating vehicle.
- There was a non-significant decrease in worker evaluations of pushing / pulling demands and shoulder postural strain when using the self-elevating vehicle.

DISCUSSION

The use of the self-elevating vehicle for stocking and picking eliminated ladder climbing and pushing ladder carts, and reduced the amount of walking, reaching above shoulder height, and torso forward bending. Consequently, both mobility issues and safety concerns associated with climbing, walking for extended periods, and pushing ladder carts were addressed. In addition, workers felt that the self-elevating vehicle reduced the physical stress associated with their job. The self-elevating vehicle should provide benefits to all workers who pick or stock from high locations and should also accommodate persons with ladder climbing or walking limitations.

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ELECTRONIC AIDS TO DAILY LIVING: AN EQUIPMENT CLASSIFICATION

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ABSTRACT

This poster session demonstrates a method of classifying Electronic Aids to Daily Living (EADLs) by output transmission. The purpose is to simplify the process of classification and to provide an indication of the functional capabilities of the EADL. This will assist in the process of a client centred assessment which is based on needs.

BACKGROUND

Electronic Aids to Daily Living (EADLs) enable people with physical and/or cognitive limitations to activate electronic appliances when they are unable to do so by the usual method. Appliances may include alarm calls, telephones, infrared remote controls, electronic beds, door openers, lights and fans. It should be noted that the Rehabilitation Engineering Society of North America (RESNA) has recommended that the term EADL be used to replace the more familiar term Environmental Controls.

An EADL may be as simple as a device to turn a light on/off by means of an ability switch or as complex as an integrated system which enables the user to activate numerous appliances in his home or workplace. The term EADL covers such a wide range of devices that it can be difficult to understand what type of equipment is implied without a lengthy explanation of its purpose, method of operation or access features. A method of classification is helpful in overcoming this difficulty and enabling equipment to be categorized.

THE PROBLEM

A useful classification should enable all types of equipment to be grouped systematically based on common characteristics. Each grouping should give an indication of the function and complexity of the EADL and should allow for new technology to be incorporated as it becomes available. A classification can become overly complex, not allow all equipment to be incorporated and not provide a good indicator of the function of the EADL.

EADLs could be classified by characteristics such as access method, process, transmission , function, availability or ease of set-up. There has been a tendency to try and use an inconsistent combination of several of these characteristics. Thus, an EADL such as the TouchScreen (direct access by means of a dynamic touch screen), which has the capability of controlling a whole environment, could be placed in a "lower" category because of its simple direct access method. A device such as the Freeswitch Max, which may be used to turn a small selection of appliances on/off could be viewed as a "higher" level device because the switch access may be used in a variety of activation modes.

DESIGN

In this classification, only one characteristic is used i.e. output transmission, in order to classify EADLs. Output transmission is the method by which information is sent from the processor of the

EADL to the appliance to be activated. This may be achieved by one or more transmission types e.g. an infrared message from a remote control to a TV. The output transmission should not be confused with the input transmission which is the method by which information is transmitted from the user to the processor of the EADL.

By using only one characteristic for classification, the EADL is simple to classify. By using the output transmission as the characteristic, an insight is gained into the complexity and function of the EADL. This is important in a client centered approach to assessment since it enables the assessor to focus first on the client's needs and wants and then use the classification table to identify which devices will meet those needs. If access methods, process or availability of the equipment were used as the classification characteristic, the focus would become the user's level of disability or the type of equipment rather than the user's needs.

In order to understand the classification, it is necessary to identify the transmission types used by EADLs. All EADLs use one or more of the following transmissions on order to activate an appliance:

- Infrared (IR) - such as is used to remotely control TVs, VCRs, drape openers
- Radio Frequency (RF) - such as is used to activate garage door openers
- Telephone line
- Wired (includes relay contacts, serial and parallel data)
- Ultrasound - such as is used by the Tash Ultra-4 line
- X-10. All X-10 utilizes AC power line carrier technology (X-10 PLC). X-10 PLC may be activated by infrared (X-10 IR) or radio frequency (X-10 RF). N.B. in the classification table below, X-10 PLC, X-10 IR and X-10 RF have been separated in order to help clarify the way in which each device interfaces to X-10 PLC.

CLASSIFICATION BY OUTPUT TRANSMISSION

- <u>Single Output Devices</u>. Devices and their components which have the capability of initiating one output transmission . For example the Adaptivation, Universal TV Remote is a single output device. It transmits infrared and is only capable of controlling audio-visual equipment.
- <u>Double Output Devices</u>. Devices and their components which have the capability of initiating two output transmissions. For example the Tykriphone is a double output device. It is capable of transmitting by phone line and X-10 and can be used to operate a telephone and several on/off functions such as lights or a call bell.
- <u>Multiple Output Devices</u>. Devices and their components which have the capability of initiating three or more output transmissions. For example the Tash Sicare Pilot is a multiple output device which is capable of transmitting by infrared, radio frequency, phone line, wire and X-10. The Sicare Pilot can be used to control numerous appliances such as audio-visual equipment, telephone, bed and light.

TABLE OF EXAMPLES OF EADLs CLASSIFIED BY OUTPUT TRANSMISSION

Classification	Description	IR	RF	Phone Line	Wired	Ultrasound	X-10 PLC	X-10 IR	X-10 RF
Single Output Devices									
	standard phone			x					
	TV remote	x							
	Garage door remote		x						
	Adaptivation, Freeswitch								x
	Adaptivation, Freeswitch Max								x
	Ablenet, Powerlink				x				
	Tash, Mini Relax	x							
	Adaptivation, Universal TV Remote	x							
	Ameriphone, RC 200			x					
	X-10, Mini Controller						x		
	Tash, Ultra-4					x			
	TYKRIS, MiniDialer			x					
	All-In-One, Universal Remote	x							
	Hytek, The Big Remote	x							
Double Output Devices									
	TYKRIS, TYKRIPhone			x			x		
	Tash, Relax II	x							x
	X-10, 8-in-1 Universal Remote	x							x
Multiple Output Devices									
	Tash, Sicare Pilot	x		x	x				x
	Madentec, Nemo	x		x	x			x	
	Independence Technologies, TouchScreen	x	x	x	x		x		
	Quartet, Simplicity Series	x		x	x		x		
	Madentec, Proxi	x		x	x		x		
	Group RT8000, Benson	x	x	x	x		x		

EVALUATION & DISCUSSION

As an ongoing project, the classification will be developed into a chart which contains a wide variety of devices. It will be then be incorporated into an assessment protocol which is being developed by the authors. The two will be evaluated for their usefulness in the clinical setting.

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GUITAR DEVICE FOR BRIAN

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ABSTRACT

A device was designed to give Brian Hughes the opportunity to learn how to play the guitar, despite his physical constraints. We successfully designed and built a simple, lightweight, and portable guitar device that Brian can assemble and use without assistance. The device uses a foot pedal to actuate a "striking rod" that hits all of the strings at once. A bicycle cable in a cable housing connects the foot pedal to the striking rod housing unit. When the pedal is tapped, the cable pulls up on the short end of the pivoting rod, causing the long end of the rod to swing down and strike the guitar strings. The result is a working guitar device that fits the need, has an appropriate and professional appearance, and is durable, safe, and easy to operate.

BACKGROUND

This device will give Brian Hughes the opportunity to learn how to play the guitar, despite his physical constraints. Brian Hughes, who is now eleven, had a stroke on the left side of his brain when he was three. Consequently, he does not have the physical coordination in his right arm and hand to strum a guitar. The objective was to design a simple, lightweight, and portable guitar device that Brian can assemble and use without assistance. Because Brian also has coordination problems in his right leg, a further objective was to have the left side of his body control the speed and rhythm of the playing.

After evaluating the alternatives, we designed and built a device that uses a foot pedal to actuate a "striking rod" that hits all of the strings at once. A bicycle cable in a cable housing connects the foot pedal to the striking rod housing unit. When the pedal is tapped, the cable pulls up on the short end of the pivoting rod, causing the long end of the rod to swing down and strike the guitar strings. The striking rod housing unit slides into and clicks into place on the aluminum clamp ("housing brace") that grips tightly to the top of the guitar's sound hole. Hence, the striking rod housing unit is removable for easy transportation and storage. Because Brian has such a dexterous left hand, and the device allows him to play the guitar in the normal position, Brian should be able to learn fingerings on the fretboard like any other beginner. The result is a working guitar device that fits the need, has an appropriate and professional appearance, and is durable, safe, and easy to operate.

Because Brian has very minimal control over his right arm and leg, he does not have the capability to play the guitar. This device will improve Brian's life by providing him with that capability. The following quote from Jane Stavely, the project supervisor and Brian's mother, describes the project's expected impact on Brian. "Brian recognizes he is 'different' from other children and that there are some things that are very difficult for him to do and other things that he cannot do at all. For instance, he has not been able to participate in organized sports like his friends or his older brother. He can't really rollerblade, skateboard or ride a two-wheel bike. Thus, Brian has turned more to artistic activities. I hope that having music as an outlet for his creative energies will boost his self-esteem (he's already talking about playing in a talent show at school!), provide him with a means to entertain himself as well as others, and maybe even stimulate the 'mathematical' part of his brain, as research seems to indicate there is a link between music and math. We may not have the next Elvis in the making (one of Brian's musical idols, by the way) but I think this project will give him a chance to achieve something he can be proud of."

TECHNICAL DESCRIPTION

This device uses a foot pedal to pull a bike cable that is attached to a polycarbonate striking rod. The rod's starting position is such that it is elevated at an angle slightly above the strings. When the user taps the foot pedal, the mechanism on the pedal pulls the bike cable, which thereby pulls the end of the rod so that the opposite end swings down and strikes the strings. A rubber band, which attaches to a hook on the striking rod and wraps around the back of the housing unit, provides a small amount of force on the cable that acts opposite to the large force from tapping the foot pedal. The rubber band rests in a groove on the back of the striking rod housing unit. The striking rod is slightly loose on the cable so that when it hits the strings the rod has some mechanical freedom from the entire cable mechanism and it is not held against the strings. Instead, when the rod strikes the strings, the rubber band pulls the rod back up preventing the rod from bouncing and allowing the strings to resonate.

The foot pedal mechanism is a modified bass-drum foot pedal. We removed the bass-drum mallet and added an aluminum L-shaped plate to which the bike cable housing attaches. The cable passes through a hole in the aluminum L-shaped plate and the end of the cable is held by a circular rotating disk that is fastened to the original "mallet rod." When the pedal is pressed, the end of this mallet rod is rotated along a circular arc away from the aluminum plate, thereby pulling the cable. The cable and cable housing extend up to the guitar where they attach to the striking rod housing unit. The striking rod housing unit holds and stabilizes the end of the cable housing. The cable, which has a stop at the end to pull the striking rod, runs passed the end of the cable housing and through a slightly loose hole in the rod. The striking rod rotates on a horizontal pin that runs through the center of the striking rod.

The striking rod housing unit attaches to the guitar via the aluminum housing brace. The brace acts as a clamp that attaches to the face of the guitar. The brace consists of a bracket and another aluminum piece that fits between the bracket and the guitar. Two Allen screws hold the brace in place on the guitar by clamping the free aluminum piece tightly against the inside face. The strings of the guitar have to be removed in order to access the two Allen screws. The striking rod housing unit slides onto the brace and clicks into position by ball detents that are located on the brace. Therefore, the brace itself is somewhat permanently attached to the guitar, but the striking rod housing unit is easily removable.

DISCUSSION

The first major challenge that we encountered was how to design the foot pedal to perform the function of pulling the cable. Our original idea was to have the cable attached to the top plate of the pedal and place a spring between the top and bottom portions of the pedal. However, the foot pedal is designed such that there is no bottom plate, just a top portion that is held in place by an arrangement of a chain and a spring. We considered removing the main plate of the pedal and attaching a bottom plate, but decided against this. We felt that using the very reliable, existing spring mechanism was a better solution, and we opted to connect the cable to the rotating mallet rod.

In the early stages of our testing, having no tension at the striking rod housing unit end of the cable caused a lot of problems. Because the system oscillated considerably, we tightened the spring on the foot pedal. We tried using a spring that pulled the striking rod up off the guitar strings to add some tension at the striking rod housing unit end of the cable. However, we found that even a loose spring was too strong and made the tapping of the foot pedal too difficult. We also needed to drill out the striking rod a little more to allow it to move independently from the cable. This allowed the rod to bounce up off the strings more when it hit them, producing a more resonant sound. The stability of the cable housing also posed a problem. The cable housing needed to stay firmly in place in order for the cable mechanism to work correctly. To achieve this at the foot pedal end, we glued the cable housing cap to the plastic, tightening holder that attaches to the aluminum plate of the foot pedal and holds the end of the cable housing. We also added an additional piece to the striking rod housing unit so to hold that end of the cable housing firmly and securely.

The last challenge was getting the rod to strike all six strings as evenly as possible. The shape of the guitar neck and bridge are such that the strings rest in a arched pattern. The striking rod is flat and originally it would not hit the end strings (the low E string and the high E string). We initially adjusted the height of the rod within the striking rod housing unit. This helped the issue but did not completely solve it. Another enormous challenge was that the exact height of the strings change depending on the specific frets that are pressed. We needed to adjust the height of the bridge and the strings by placing thin layers of cardboard beneath the bridge. Finally, we filed small notches where the center strings (A, D, G, B) rest to make the rod touch all six guitar strings. This solution worked, but it should be noted that our modifications made the strings just slightly more difficult to press down than they were originally. However, the strings of the small guitar are still quite easy to press down relative to other guitars.

The primary limitation of our device is that Brian will not be able to pick individual strings. Every time he taps the foot pedal, the rod will strike all the strings so that Brian will only be able to play chords and chord progressions (unless he learns how to mute specific strings). However, both Brian and his mother understood this limitation when they chose this simple "striking" mechanism. If Brian really excels with this device and decides he would like to improve his device, future projects may involve giving him the option of picking individual strings. In future attempts at making a device similar to ours, we feel that the sound quality might be slightly improved by having a layer of a softer material on the bottom of the striking rod. The polycarbonate rod produces a sound slightly brighter than that produced by strumming the strings with one's thumb. The sound quality might be improved slightly by using dense rubber pads to hit the strings, or something similar to the pads that strike the strings of a piano.

SUMMARY AND CONCLUSIONS

The result of this project is a Guitar Device for Brian that successfully fits the need and meets all of our project objectives. Brian will control the device using his left arm and left leg. The device is lightweight and portable. It is incredibly simple! Brian can assemble and use the device without anyone's assistance. Also, Brian will have direct control over the rhythm and speed of his playing. The finished product has an appropriate and professional appearance. It is safe, durable, and easy to operate. Furthermore, the final budget of $271.93 was well below the five-hundred dollars allotted.

We have thoroughly enjoyed working on this project. Seeing Brian's wonderful attitude and his tremendous enthusiasm really inspired us to do our very best. Working with Brian and accomplishing our goals for this project resulted in an incredibly rewarding and beneficial experience for us. In conclusion, we truly hope that this device is just as rewarding and beneficial for Brian.

Functional Control and Assistance (Topic 5)

Prosthetic Socket Fabricated Using Selective Laser Sintering: A Case Study

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ABSTRACT

Prosthetic socket CAD/CAM techniques are combined with selective laser sintering technology (SLS) to produce a sophisticated double walled monolithic prosthetic socket. The socket features selective reinforcement, variable wall compliance, and an integrated pylon attachment. It was manufactured for a 65-year-old transtibial amputee using a socket shape identical to his current definitive socket. A prosthesis was assembled using the same foot as the subject's definitive prosthesis. A subsequent gait analysis showed no significant difference in ambulation between the SLS prosthetic limb and the conventional one.

BACKGROUND

CAD and Computer Assisted Manufacture (CAM) techniques are beginning to be widely used to design and manufacture sockets. A mechanical digitizer, magnetic digitizer, or a non-contact laser scanner inputs the residual limb shape into the computer (1). The prosthetist then uses specialized software to produce a biomechanically correct socket from the limb shape. A computer controlled milling machine carves the pattern for the socket from plaster or foam. The socket is then made using conventional methods such as vacuum molding or lamination.

The limitation of currently available prosthetic CAD systems is that they only design the shape of the inner wall of the socket, which is all that is necessary for conventional fabrication. They do not actually design the three dimensional shape of the socket including the wall thickness.

In SLS, components are built by material addition rather than by material removal by using a directed laser beam that causes individual particles to adhere in selected regions of space. The process begins by first depositing a thin layer of powder into a container. The powder surface is raster-scanned with a laser beam. The intensity of the beam is modulated to sinter the powder in areas to be occupied by the part at that particular cross-section. In areas not sintered, the powder remains loose and is removed once the part is completed. Successive layers of powder are then deposited and sintered until the entire part is complete.

Similar technology has been previously used to fabricate prosthetic sockets (2,3). The previous efforts produced sockets similar to those manufactured by conventional means.

RESEARCH QUESTION

The objective of this study was to test the feasibility and reliability of a SLS fabrication by developing a monolithic flexible wall socket design, incorporate the socket into a functional prosthesis, and to quantitatively compare gait performance with a conventionally fabricated socket.

METHOD

A single male transtibial amputee, age 65 was recruited for test purposes. He was a representative of a typical elderly dysvascular transtibial amputee and would be considered an unrestricted indoor and limited community level ambulator. The amputee had a well mature residual limb. His existing prosthesis was a PTBSC socket with an Alpha liner, ultra-light endoskeletal, alignable system with a Seattle Lite foot.

The definitive socket pattern from the subjects existing prosthesis was measured using a laser imager and served as the template for SLS socket fabrication. Trim lines, load bearing areas, and pressure sensitive areas were marked in black on the pattern (fig 1). The laser imager captured these marks. The surface shape data and the marked locations were saved in an AAOP data interchange file. The AAOP file was emailed to University of Texas to create a final three-dimensional socket design from the input data.

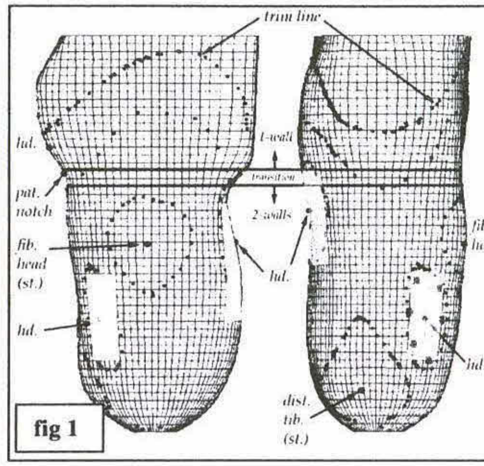

fig 1

Numerous labor-intensive software steps were required to create the three dimensional socket design from the shape of the inner surface of the socket. The socket was then manufactured on a SinterStation 2000 at the DTM Corporation in Austin.

The socket differs in several ways from a conventional socket. There is a rigid 0.115" outer wall and a flexible 0.040" inner wall. The inner wall was locally modified to provide additional reinforcement in load bearing areas and more flexibility in sensitive regions.

There are three stiffened regions. These areas are the anterio-lateral, medial, and popliteal areas. These areas have an inner wall thickness of about 0.115 and additionally have support struts connecting the inner and outer walls (Marked hd in fig. 1).

The regions of the distal anterior tibia and the fibular head incorporate variably compliant areas. Each compliant area consists of a hexagonal set of triangular cantilever beams composed of radial slots in the inner socket wall (fig 2). These were designed to deflect 0.08" under the maximum design pressure.

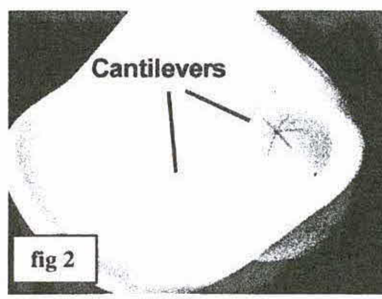

fig 2

The final design feature is a distal fitting for a nylon pylon adapter. The nylon pylon adapter is a prototype design from Seattle Limb Systems. The distal fitting is a 1" deep cylinder with a 1/4" wall thickness. To accommodate high stresses at the pylon to socket interface, the outer wall of the socket is thickened to allow a smooth transition to the cylindrical fitting.

A design compromise was made in deciding not to shape the top of the socket to the socket trim lines. This was done partially to simplify the design process and partially to ensure proper fit. The trim lines on the model were made based on experience with other materials and other designs.

The subject was fitted with the SLS socket prosthesis and aligned using visual gait observation and patient feedback. Quantitative gait analysis was performed using a Vicon 370 system with 6 cameras. Immediately following each test session the subject rated socket comfort and overall ease of ambulation using a 0-100 point visual analog scale.

RESULTS

Visual analog scales score (0-100) scale) for socket comfort was higher for the SLS socket while overall ease of walking was similar (Table 1). Walking with the SLS socket resulted in a 3% increase in self-selected speed and improved step length symmetry between the prosthetic and intact limb. Stance phase duration and double support were similar though slightly greater when using the SLS socket design.

Although the use of a single subject prevents meaningful statistical analysis and limits the interpretation of quantitative gait and function comparison, the results of the subject performance is supportive of a useful role of SLS variable wall complaint sockets. Several areas of design improvement and socket fabrication need to be further explored before this technique could be tested in larger scale clinical studies.

Table 1	SLS Socket	Conventional
Walking speed (m/s)	78	74
Prosthetic Stance (% stride)	65	61
Intact Stance (% stride)	62	62
Prosthetic Double Support (% stride)	26	24
Intact Double Support (% stride)	30	28
Prosthetic Step Length (m)	.46	.43
Intact Step Length (m)	.47	.55
Socket Comfort (0-100)	78	68
Ambulation Ease (0-100)	60	63

First, long term durability and structural integrity need to be demonstrated. Destructive testing of the socket, with a special emphasis on the pylon attachment areas is planned.

A second major concern with freeform fabrication is the cost of socket manufacture. The estimated cost of manufacturing the SLS socket was approximately $1500 exclusive of casting and socket modification labor

Third, the SLS socket computer design requires a high level of engineering expertise. While currently this is cost and time prohibitive, most of the steps in the socket design can be automated and appropriate software development.

Further clinical testing is needed. Optimally the subject would have been given a longer period of acclimatization in order to realistically assess subjective comfort and acceptance.

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fig 3

ACKNOWLEDGEMENTS

Thanks to the DTM Corporation for material and machine time necessary to manufacture the SLS prosthetics socket.

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FORCE CUES APPLIED DURING SIMULATED DRIVING CAN MOTIVATE PARETIC UPPER LIMB USE

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ABSTRACT

Constraint-induced (CI) movement therapy is a rehabilitation strategy that has been shown to help stroke patients regain function in their upper limb. This paper introduces a method to automate the CI therapy technique using force cues administered in the context of steering tasks. Our preliminary results using a split-wheel equipped driving simulator, Driver's SEAT, suggest that force constraint cues can motivate stroke subjects to increase their involvement of the paretic limb in bilateral steering tasks.

BACKGROUND

Stroke, the third leading cause of adult disability in the United States, commonly results in a condition characterized by loss of motor function in the upper and lower limbs contralateral to the side of the cerebral injury. The most effective strategies to help stroke survivors recover maximal motor function in their affected limbs are those that encourage them to actively involve their paretic limb in activities of daily living (ADLs) (1).

One of the most promising therapy strategies, constraint-induced (CI) movement therapy, hypothesizes that unsuccessful attempts to use the paretic limb immediately after a cerebral shock result in compensatory use of the non-paretic limb, leading to the learned non-use of the paretic limb. CI therapy focuses on constraining the non-paretic limb and encouraging use of the paretic limb through training activities and involvement in real-world tasks (2). A recent study by Miltner *et al.* with 15 subjects (2 were sub-acute) who benefited from receiving CI therapy, suggests that this therapeutic strategy may also be effective for sub-acute stroke subjects (3). These results support our development of the Driver's Simulation Environment for Arm Therapy (Driver's SEAT), a device that is being used to explore CI therapy strategies.

RESEARCH QUESTION

The main objective of this study is to determine whether patient-mediated constraining force cues can motivate subjects with hemiparesis to use their paretic limb instead of their non-paretic limb during bilateral steering tasks administered via Driver's SEAT. This study will help determine the potential long-term effect of the experimental therapy and carry over to ADLs.

METHOD

Experimental Apparatus: Designed and built at the VA Palo Alto RR&D Center, Driver's SEAT (Figure 1) incorporates a modified PC-based driving simulator, a novel split steering wheel, along with force reflection strategies to create motivating unilateral and bilateral steering tasks. Driver's SEAT was designed with three therapy modes, called passive movement (PM), active steering (AS) and normal steering (NS) [Detailed description in Johnson, *et al.* (4)].

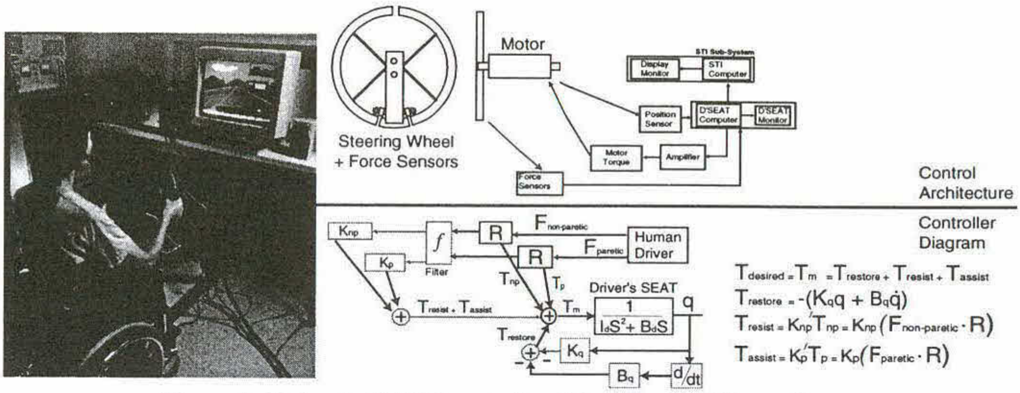


Figure 1: Driver's SEAT control architecture and flow diagram.

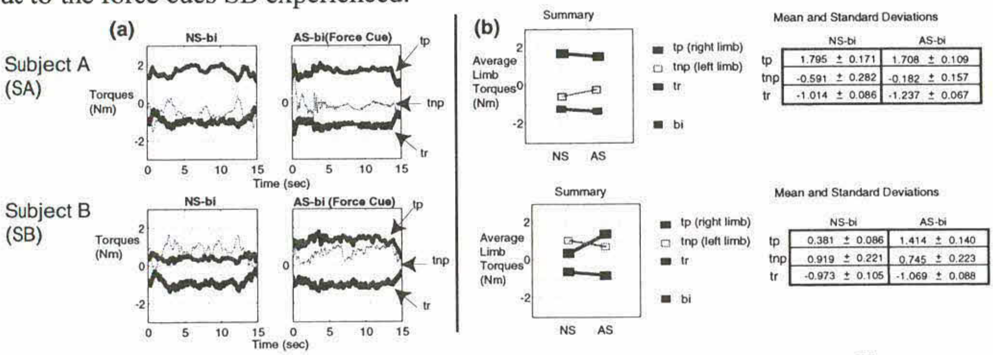
Our controller design (Figure 1) implements a force reflection strategy that allows our key therapy mode (AS) to administer a modified CI therapy technique to constrain the non-paretic limb and engage the paretic limb during the performance of a bilateral steering task. To discourage the non-paretic limb, subjects experience a constraining force cue when using the non-paretic limb to steer, i.e., the wheel moves only when the measured tangential force from the paretic limb is greater than the force from the non-paretic limb. The NS, or diagnostic, mode allows us to evaluate "natural" force involvement of both limbs in the bilateral steering task. No force constraint cues are used in this mode and the wheel responds to both limbs.

The novel split steering wheel is a key component in our control design. It allows us to independently measure, via force sensors located on the rim, the tangential forces applied to the wheel by both limbs, F_p and F_{np}. The control algorithm, illustrated in Figure 1, is governed by the general control law $T_{desired} = T_{restore} + T_{resist} + T_{assist}$ where T_p and T_{np} are limb torques, K_p and K_{np} are the compensation gains and q is the steering wheel position. In the NS mode, the torque output to the wheel is the restoring torque, $T_{restore}$, which gives a "car-like" feel to the wheel. In the AS and PM modes, the torque output to the wheel is the restoring torque combined with one of the terms designed to oppose one of the two limb torques, T_{resist} or T_{assist}.

Test Procedure: Neurologically normal subjects and subjects at least 6 months post stroke with stable neurological deficits, intact cognition and some volitional movement in their paretic limb participated in the study. Subjects sat in a wheelchair and completed unilateral and/or bilateral steering tasks in each mode. The essential tracking task was to steer their simulated vehicle on a 50-second drive containing three different road curvatures. Subjects were instructed as to which limb should control the wheel. Force, position, and lateral steering dynamic information was collected. Electromyographic signals were collected from surface electrodes placed over seven key arm muscles. Two cameras monitored postural movements.

RESULTS

Figure 2 shows sample forces from a neurologically healthy subject (SA) and a stroke subject (SB) steering the right turn (RT) of a bilateral steering task with (AS-bi) and without (NS-bi) force cues. SA is a 72 year old right-handed male subject. SB is a 2 year post-stroke right-handed female subject (age = 54 years) with right hemiparesis. In Figure 2a, SA's right limb torques were relatively the same for NS-bi and AS-bi but SB's torques changed significantly ($p<0.05$). SB switched control of the wheel from her non-paretic left limb to her paretic right limb. Figure 2b shows that the average torque effort of SB's paretic limb increased from N-bi to A-bi* while the average torque effort of her non-paretic limb decreased. We believe the changes are due to the force cues SB experienced.



	NS-bi	AS-bi
tp	1.795 ± 0.171	1.708 ± 0.109
tnp	-0.591 ± 0.282	-0.182 ± 0.157
tr	-1.014 ± 0.086	-1.237 ± 0.067

	NS-bi	AS-bi
tp	0.381 ± 0.086	1.414 ± 0.140
tnp	0.919 ± 0.221	0.745 ± 0.223
tr	-0.973 ± 0.105	-1.069 ± 0.088

Figure 2: Subject A and B non-paretic and paretic limb torque profiles

DISCUSSION

In the NS-bi tasks, hemiparetic subjects such as SB chose to use their unimpaired limb over their impaired limb to control the outcome of the bilateral task. Healthy subjects such as SA did not exhibit significant preference for one limb over another. In the AS-bi tasks, subjects with hemiparesis did increase the torque effort from their impaired limb but struggled to avoid using their unimpaired limb in the exercise task. Healthy subjects, while not needing to increase their limb effort, also struggled to not involve their other healthy limb in the task. Our on-going study will continue to evaluate the efficacy of this intervention for individuals with post-stroke hemiplegia.

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THE EFFECTS OF PROSTHETIC SOCKET DESIGN ON TRANSTIBIAL AMPUTEE RESIDUAL LIMB CIRCULATION

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ABSTRACT —Magnetic resonance (MR) angiographic and vascular perfusion measurements [Debatin and Hany 1998; Pelc 1995; Botnar, et al. 1996; Masui, et al. 1995; Caputo and Higgins 1992] were used together with finite element analyses [Houston, et al. 1998] in this study to quantitatively assess the effects of prosthetic socket design variations and prosthetics loading on transtibial amputee residual limb tissue circulation. Study results showed patellar tendon bearing (PTB) socket designs frequently occlude flow in patients' popliteal arteries, even precipitating stasis with loading if socket popliteal depressions are not optimally designed.

INTRODUCTION — It is commonly assumed that prosthetic socket designs do not adversely impact amputee residual limb tissue circulation, or the issue is just ignored for lack of substantive information. This is an extremely important problem, however, since approximately eighty percent of all lower limb amputations are performed due to complications from peripheral vascular disease [Graves and Kozak 1998]. It is known that tissue strains from improper socket designs and/or excessive prosthetic popliteal loading can compromise amputee residual limb tissue circulation [Levy 1983]. But prosthetic compromise of tissue circulation is all too frequently only clinically recognized when cases become egregious, with acute ischemic pain and imminent tissue trauma. Unfortunately, there are no hard and fast rules that clinicians can use to ensure prosthetic circulatory compromise does not occur.

RESEARCH QUESTION — The objective of this study was to investigate the effects of prosthetic socket design geometry and applied prosthetics loads on transtibial amputee residual limb tissue circulation, and determine if tissue circulation sensitivities to socket design variations were sufficient to enable optimization of respective design parameters.

METHODS — Six male, unilateral transtibial amputees, ranging from 46 years to 81 years of age, and from 2½ years to 55 years post amputation of either traumatic or vascular origin, with residual limbs between 10 cm and 32 cm in length, with typical amounts of tissues ranging in stiffness from soft to average durometer, who had successfully used a prosthesis without undue complications for the previous two or more years, and whose prostheses' fit and function were deemed acceptable using established, conventional, prosthetics methods [NYU P&O 1982], as well as by the subjects' own assessment, were recruited as experimental subjects for the study. Exact, all plastic, duplicates of the subjects' sockets were made, together with harnesses with elastic side straps to secure the experimental sockets on the subjects' residual limbs under a 32 kg proximally directed axial load.

The VA NYHHCS Radiology Service, Picker International, Inc. 1.5 Tesla magnetic resonance scanner, contrast angiographic imaging and advanced quantitative perfusion measurement software were tested and calibrated using Picker and University of Michigan fixed radiographic phantoms, and an especially modified Cobe Laboratory heart–lung peristolic perfusion pump with 1.0 Hz pulsatile flow and with constant flows of water at 2, 5, 10, and 15 ml/sec. Magnetic resonance angiograms of the subjects' residual limbs (RL's), from the medial tibial plateau (MTP) to the distal end, were then acquired with the subjects' RL's inside a cranial–cervical coil in a fixed skeletal alignment, without and with their respective experimental duplicate sockets on under 32 kg proximally directed axial loads. Flow velocities and volumes were also measured in the subjects' popliteal arteries at the MTP–2.5 cm level, in cardiac synchrony, without and with their respective experimental duplicate sockets on under 32 kg axial loads. A series of finite element analysis simulation studies, together with fittings of corresponding experimental sockets, were performed in which the anteroposterior (AP) dimension at mid-patellar tendon (MPT) level, popliteal depression proximodistal (sagittal plane) radius of curvature, proximodistal height, and transverse section mediolateral radius of curvature were serially varied, were then constructed for the 58 year old subject with average durometer tissue and 12 cm long residual limb. The popliteal artery perfusion velocity and volume measurements were repeated without and with each of the respective experimental sockets on the subject's residual limb under a 32 kg axial load.

RESULTS — The MR angiographic mappings acquired in the study showed diminution of the subjects' residual limb vasculature. In four of the subjects, it was possible to trace their popliteal and posterior tibial arteries distally to within a few centimeters of the end of their residual limbs. However, flow in their anterior tibial and peroneal arteries was so diminish (or nonexistent) that they were not visible in the angiograms. In one of the remaining subjects, popliteal arterial flow vanished approximately 3.5 cm below MTP level. There was no measurable flow in his distal posterior or anterior tibial or peroneal arteries. In the sixth subject, an 81 year old male with a 10 cm long residual limb, 55 years post traumatic amputation, only his medial genicular arteries evidenced measurable perfusion. Flow in his femoral/popliteal artery vanished above his femoral condyles. The close proximity of the medial genicular arteries to the limb surface, imposed special prosthesis design constraints to avoid occlusion of the subject's sole residual limb vascular supply. A fact not previously documented in his medical or prosthetic treatment records. In hind sight, this should have been evident from the subject's long standing, chronic bouts of (undoubtedly ischemic) pain following extended usage over an eight to ten hour work day of his PTB prosthesis with femoral cuff suspension strap.

Measurement of popliteal arterial flows at the MTP–2.5cm level in the four subjects with appreciable perfusions, revealed average net antegrade flow volumes of +1.6 ml/cardiac cycle with peak antegrade flow velocities of +385 mm/sec, and peak retrograde velocities of –96 mm/sec, in a "natural", unperturbed, resting state without prosthetic socket. With the plastic duplicates of the subjects' current prosthetic sockets donned and 32 kg axial compressive loads applied (approximately ¼ body weight), the perfusion volumes and velocities were markedly altered. In two of the subjects, the net antegrade flow volumes decreased to +0.8 to +0.9 ml/cardiac cycle, while peak average flow velocities increased to +435 mm/sec antegrade, and peak velocities of –326 mm/sec retrograde. In a third subject with a higher posterior socket brim and pronounced socket popliteal depression, the average net flow volume in his popliteal artery dropped to –0.07 ml/cardiac cycle, with average peak velocities of +587 mm/sec antegrade and –522 mm/sec retrograde, indicating vascular stasis. Circulation with supply of blood and metabolites to and removal of fluids, metabolic wastes and by products from, this subject's residual limb tissues thus was only able to occur when he removed his weight from his prosthesis thereby unloading his tissues. The fourth subject exhibited vascular flow with prosthetic loading that was more restricted than the first two subjects, but not as severely compromised as the third subject.

To investigate whether socket design parameters could be optimized to minimize the impact of prosthetics loading on residual limb tissue stresses and strains and circulation, a series of finite element analysis simulation studies, together with fittings of corresponding experimental sockets, were performed for one of the subjects. Results from these studies [Houston 1998] showed that prosthetic socket design parameters can indeed be optimized. Too large of socket MPT AP dimensions were shown to allow the subject's limb to sink into the socket, creating excessive tissue strains between the stiff posterior socket wall and his rigid posterior tibial epicondyles, compressing his popliteal artery and occluding circulation. Too small of an AP dimension produced similar results. Too high of a posterior brim similarly was found to "trap" the popliteal artery between the posterior socket wall and the tibial epicondyles, occluding flow. Too low of a posterior brim did not provide sufficient anteroposterior and vertical support, so the limb slipped posteriorly and distally, compressing the popliteal artery. Similarly, too large of a popliteal depression proximodistal radius of curvature was found to fail to provide sufficient support for the limb, and distal migration with excessive popliteal artery compression occurred. Too small of a proximodistal radius of curvature led to large gradient shear forces in the politeal tissues that occluded tissue circulation [Bennett, et al. 1979]. Too large of a popliteal depression mediolateral radius of curvature also failed to provide adequate support, creating excessive stresses and strains on the hamstring tendons, medial tibial condylar flare and proximal popliteal tissues at the socket brim. Too small of a mediolateral radius of curvature created excessive popliteal tissue normal and gradient shear stresses, occluding tissue circulation, and increasing the likelihood of tissue ischemic and mechanical trauma.

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A REAL-TIME SIMULATION SYSTEM TO EVALUATE USER-DEVICE INTERACTION: AN APPLICATION FOR DEVELOPMENT OF FNS CONTROL SYSTEMS

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ABSTRACT

With many assistive devices, user performance is degraded by time-delay and dynamic properties of the system response. To achieve better performance, the design and development process should address issues raised by the dynamic interaction between the user and the device. A real-time stimulation (RTS) system has been developed with an architecture that provides many of the advantages of using computer models in the development process, yet retains the critical interaction between the user and the device. An example study is described that uses the RTS in development of control algorithms for a Functional Neuromuscular Stimulation (FNS) system. The RTS is currently being used to evaluate design strategies and to assist in user training.

INTRODUCTION

Functional Neuromuscular Stimulation (FNS) is a rehabilitation technology aimed at restoring partial use of limbs which are paralyzed due to traumatic spinal cord injury. A stimulator electrically activates the affected muscles to cause functional contractions. Several FNS-based clinical devices are available for tasks such as hand grasp [FreeHand System, NeuroControl Corp., Cleveland, OH], bladder and bowel control [VOCARE System, NeuroControl Corp.], and weight supported standing [Parastep System, Sigmedics Inc., Northfield, IL]. Inherent muscle properties, such as time delays and recruitment nonlinearities, make FNS control difficult and limit its use for unstable mechanical systems such as unsupported (hands-free) standing (1),(2). To overcome these control challenges, a host of sophisticated control methodologies have been developed (1),(3),(4). User interaction with animal (5) and limited mathematical (5),(6),(7) models has been studied.

PROBLEM STATEMENT / RATIONALE

Experimental evaluation of FNS control strategies is expensive and time consuming. Offline computer simulations facilitate development, but they do not account for the dynamic interaction between the user and the device. Real-time dynamic simulations that allow user interactions are needed to provide a platform for efficient and effective development of FNS control systems.

DESIGN AND DEVELOPMENT

The purpose of the current work was to develop a real-time simulation (RTS) system which integrates the potential FNS user into the control system design. The RTS (Figure 1) acquires real-time input from the user, simulates the dynamic equations of a system model, and graphically displays the system output to the user. The strength of the RTS is the ability to extensively test various control methodologies, thereby allowing the designers to iteratively improve the overall system performance. Furthermore, the RTS can be used to help train novice users on a virtual device thereby reducing the required training time on the actual device.

The RTS system has a modular design with 6 major components (Figure 1). The USER is presented with a task defined in terms of controlling system output variables. S/he monitors the system status on the DISPLAY UNIT then provides input to the control system through an INPUT

DEVICE. The CONTROLLER then acts on a SYSTEM MODEL that represents the system to be controlled. Finally, the model output is reported to the display via a SENSOR MODEL, which may include dynamics or noise representative of the real sensors. Notice that the user input and potentially the display can be the actual devices used in the end-product; thereby allowing the user to evaluate and become familiar with the input and display devices as well as the controller and the system. To date, we have implemented and evaluated linear and nonlinear neural network controllers that acted on simple linear systems and on complex nonlinear musculoskeletal models. Finally, the sensor properties can range from a simple gain to complex properties including delays, dynamics, and noise. The RTS also provides the capability of real-time signal processing and data logging of the user's performance.

The RTS is programmed in LabView 5.1, which provides an environment to develop a graphical user interface (GUI), perform numerical computations, and interact with the environment through an A/D board or standard ports (i.e. serial, parallel, PS2 ports). The RTS applications have been run on a standard Pentium-based PC.

EVALUATION

The RTS has been used in a set of experiments to test various control strategies for controlling coronal plane standing posture using FNS. This study is briefly presented to demonstrate the capabilities of the RTS system. In this experiment, the musculoskeletal properties of a subject standing with FNS were modeled as a 3-segment mechanical system acted upon by two electrically stimulated muscles. The model included passive stiffness and damping, nonlinear muscle recruitment, muscle activation dynamics and delay, and torque-angle / torque-velocity properties. The electrical stimulator was also modeled including quantized output and a fixed stimulation frequency. The model output was reported via a sensor model, which included random noise in some trials. Several control systems were evaluated that include linear feedback and nonlinear neural network feedforward components. This model used a simulation timestep of 0.01 seconds with a stimulation period of 50 msec.

Two protocols were performed by two subjects each (4 total subjects). Each subject performed 6 trials in evaluating 5 controller combinations. These studies lasted about 1 hour including at least 45 minutes of virtual stimulation. Note that it would have been impossible to perform these trials using stimulated muscle due to fatigue.

Figure 2 presents raw data that compares user performance with two different controllers (6 trials). Here the user was asked to transition from an initial posture to upright. The desired and actual postures are shown. Other trials with the RTS compared the performance of five different control systems for various tasks with and without sensor noise.

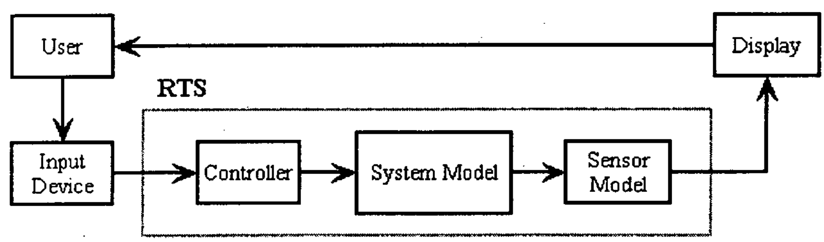

Figure 1: The Real-Time Simulation (denoted in grey) receives input from the user and processes the signal using the specified controller before applying the signal to the system model. The system model output is then modified by the sensor model and displayed.

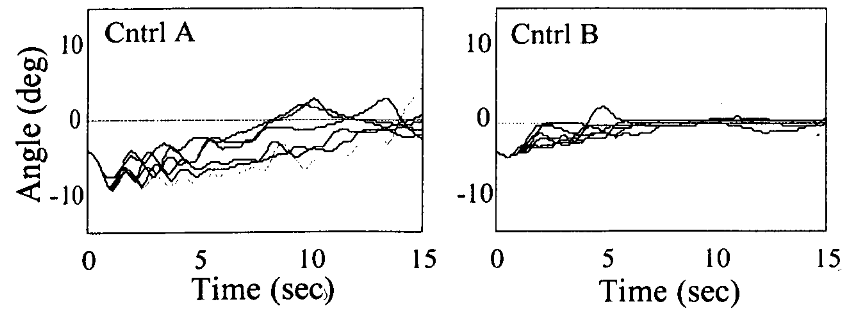

Figure 2: Results from trials using feedback (Cntrl A) and adaptive feedforward (Cntrl B) controllers are compared using the RTS. Notice that control appears better and is more repeatable with Cntrl B.

The RTS system has also been used in our lab for subject training prior to experimental trials and to demonstrate the complexities of FNS control. These applications used a swinging leg musculoskeletal model rather than the model described above.

DISCUSSION

A real-time simulation system has been developed which allows evaluation of user-interaction with dynamic systems. The modular design of the RTS allows for exchange of control systems and models as well as user input and display devices. An example study using the RTS is presented which demonstrates the differences in user performance with two different FNS control systems.

The system can be used to evaluate candidate control methodologies or input devices, to assess sensitivity to system properties or noise, or to train novice users in the operation of a device. As a design/development tool, the RTS system may reduce the time required for experimental evaluation of the actual system. As a training tool, it may reduce the length of the learning curve with the actual device and may reduce some of the risks involved in its initial use. The ability of the system to work autonomously in preprogrammed or performance-based protocols (where the protocol is modified based on real-time analysis of subject performance) and to document subject progress makes it an attractive tool for clinical as well as research applications.

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IMPLEMENTATION OF AN IMPLANTABLE JOINT ANGLE TRANSDUCER

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ABSTRACT

An implantable joint angle transducer (IJAT), using Hall effect magnetic sensors, was implanted around the wrist joint in two subjects with C6 level spinal cord injury. These subjects also used an implanted ten-channel neuroprostheses for functional hand grasp. The titanium packaged sensor was implanted in the radius while a similarly packaged magnet was implanted in a carpal bone (the lunate). The IJAT replaced the external shoulder-mounted controller and provided command-control information for chronic use. The device has remained functional for almost two years and provides excellent control of hand grasp.

INTRODUCTION

Functional neuromuscular stimulation (FNS) restores function in individuals with quadriplegia or paraplegia by stimulating muscles with upper motor neuron type of paralysis. In upper limb applications in subjects with quadriplegia, hand grasp and release has been successfully achieved (1). Muscles are stimulated with an implanted stimulator to activate hand muscles in selected patterns. This allows functional grasp patterns. A fully implantable system has been implemented (2). The stimulator is powered and controlled by an external unit, communicating through a transcutaneous radio-frequency powered link.

A command control signal, generated by the neuroprosthesis user is required in order for the user to have voluntary control over the muscle stimulation patterns. In paralyzed individuals, especially cervical level spinal cord injury, the options for deriving a voluntary controlled command control source are limited.

Wrist angle has been used for command control. To use the wrist for control, active wrist extension is required (C6 or lower injuries), while gravity flexes the wrist. Ipsilateral wrist control has been implemented in some subjects using an externally mounted transducer. External transducers have been viable for first generation systems, but have inherent limitations (3). They require donning and doffing, provide inconsistent signal quality because of changes in mounting, are not cosmetically appealing, may encumber some activities, and may become dislodged during use. Such limitations led to the development of an implantable joint angle transducer (IJAT) capable of sensing movement of the wrist (3) and its clinical implementation.

METHODS

Hardware

The IJAT transducer consisted of 3 Hall effect sensors assembled on an alumina substrate. This was attached inside a titanium capsule. Stainless steel leadwires were welded to the outer part of feedthrough pins. The IJAT was connected with these lead wires to the implanted stimulator-telemeter (IST). Within the IST, the three sensor signals were differentially amplified, sampled and digitized. This digital information was transmitted out of the body using digital coding of the RF signal. Cylindrical Neodymium-Iron-Boron (NdFeB) permanent magnets, similarly packaged in titanium capsules, were used. Both titanium capsules were designed as threaded cylinders for insertion in the intramedullary region of the target bones.

Surgical Procedure

The threaded implants were inserted using cannulated tools specifically designed for the IJAT. The magnet was inserted in the lunate and the IJAT transducer capsule in the lower end of the radius. The IJAT leads were connected to the implanted IST with in-line connectors. The forearm was casted for four weeks followed by physical therapy.

Subjects

The clinical data for the two subjects is shown in Table 1.

Table 1: Clinical data for the two subjects.

Subject	**1**	**2**
Age at injury	21	28
Cause of injury	Fall	Diving accident
Injury Level:	Right: C6 (OCu:2) Left: C6 (OCu:3)	Right: C5(O:0) Left: C6(OCu:2)
Age at IJAT implant	23	48
Years post-injury	2	20
Side on which IJAT & IST implanted	Right	Left

Control Signal Assessment and Usage

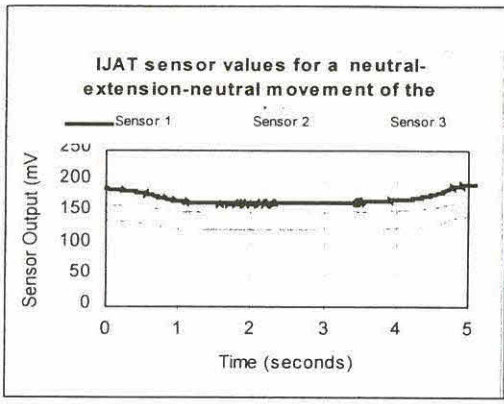
Sensor signals were recorded approximately monthly. The range of the sensor signals were recorded for full voluntary wrist extension from a position of gravity aided flexion. Command control was initiated by the subject pressing a wheelchair mounted switch with his contralateral arm. The wrist with the implanted IJAT was held in a steady position for 1 second while baseline IJAT values were collected. These values defined the zero position on a lookup table. Following this, the hand could be used for different grasp patterns, which were selected by pressing the external switch repetitively. Once the grasp pattern was selected, the command control routine used the lookup table to assign a wrist flexion-extension angle depending on the IJAT sensor values. This angle was then used, in a second lookup table, to find the stimulation parameters for that particular grasp. The second table was constructed so that it progressed through stimulation parameters for progressively closing the hand as the wrist was extended. Flexing the wrist reversed the process and allowed the hand to open.

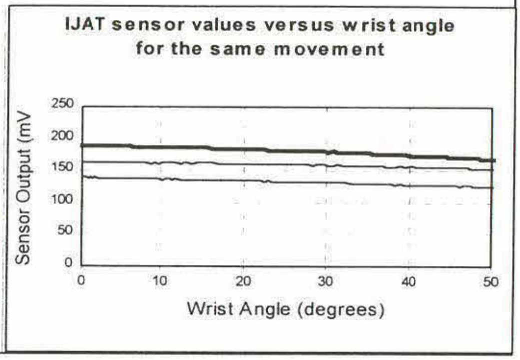
Functional Assessment

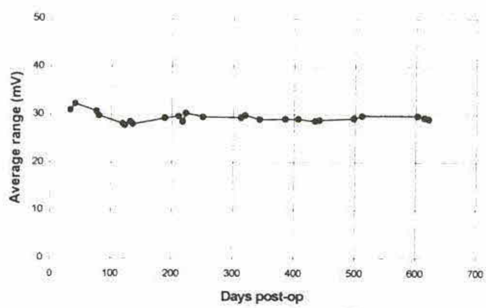
Functional results were assessed using the grasp release test (4). In this test, the subject had to grasp, transfer and release objects in a horizontal workspace. The number of successful transfers over 30 seconds for each of six different objects were recorded. All trials were randomized and the set of six objects was repeated three times for each control system used . The IJAT was compared with control using an external wrist angle transducer.

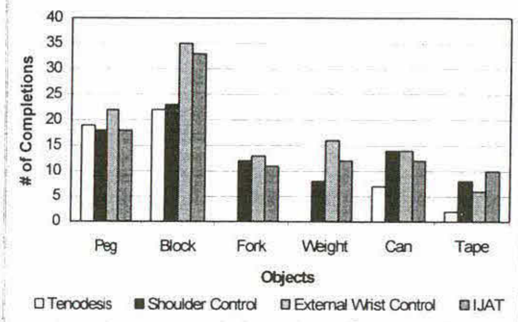
RESULTS

Figure 1 shows, on the left, representative IJAT signals for a typical extension wrist movement. On the right, the same movement is displayed as IJAT signals versus wrist angle. This range is sufficient to allow approximately 30 command levels in the control scheme. Figure 2 shows the stability of the IJAT signals over time. Figure 3 shows the results from the grasp release test. The IJAT performs similar to both external shoulder control and external wrist control systems. We have thus demonstrated feasibility and functionality of a fully implanted transducer as a command control unit for an implanted muscle stimulation system.









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DEVELOPMENT AND TESTING OF A NEW BIOFEEDBACK SYSTEM

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ABSTRACT

Resourceful use of biologic signals to provide an interesting and motivating exercise experience to patients during rehabilitation is the core of this project. The signal from an electromyographic (EMG) biofeedback unit is used as input into a computer based system to control cursor movement in computer games. Clinical testing of the BioRehab System demonstrates positive responses from both patients and clinicians. Clinical trials have been initiated.

BACKGROUND

Movement has been described as being central to human life (1). Movements are learned early in life (motor learning) and modified into patterns that are used to perform specific tasks (functional movements). The ability to sequence movements into specific patterns (motor control) is developed and modified throughout the human life span in order to accommodate new interests and perform various functions in daily life. An interruption in the ability of a person to move even one body part can threaten the capability of the person to independently perform many functional tasks (movement impairment). Movement impairments can result from an injury or malfunction in any neurologic or biomechanical system of the body (2). Rehabilitation is the process by which patients receive treatment to reduce movement impairments and are reeducated in functional movements (1).

Physical and occupational therapists provide rehabilitation treatment to individuals with movement impairments to gain or restore functional movements. During rehabilitation, patients are taught how to move correctly and are given exercises to diminish their movement impairments and increase their motor control (2). To correctly learn movements and exercises, patients often require many repetitions of instructions from the therapists (3). Patients must cooperate in their rehabilitation by practicing the movements and performing the exercises independently.

Biofeedback is a well recognized motor learning and motor control therapy technique. With training and practice, subjects can learn how to control parts of their body for which the conscious control or the perception of control has been interrupted. EMG biofeedback has been used in the rehabilitation of persons having neurologic or biomechanical motor impairments. Clinicians often relate how excited patients become when first introduced to biofeedback using traditional biofeedback equipment. However, motivation to continue practicing movements and exercising using traditional biofeedback often wanes and patient progress ceases as the novelty of using the biofeedback device wears off and subjects become bored or disinterested in the feedback displays. This is especially evident with patients involved in long-term rehabilitation programs such as individuals recovering from a stroke or other catastrophic illnesses. In a study assessing the efficacy of traditional EMG biofeedback in the treatment of patients following stroke, Wolf, et al, noted the important contribution motivation played in positive outcomes from biofeedback treatment (4). A direct relationship between patient compliance with therapy and decreasing movement impairment has been demonstrated (5). Lack of motivation to continue with practice is detrimental to progress in a rehabilitation program (6).

STATEMENT OF THE PROBLEM

The primary clinical problem addressed by this project is the need for an engaging form of biofeedback to encourage continuation of motor control and motor learning activities and exercises in patients with movement impairments.

RATIONALE

The concept of incorporating entertainment with exercise equipment is uncommon in rehabilitation medicine although it is common in other exercise applications. Many exercise facilities have equipment for exercise such as the stationary bicycles and rowing machines that have incorporated television screens and various computerized racing routines and exercises to enhance the motivation of people using the equipment. Rehabilitation applications of exercise equipment have not been as highly developed within existing technological capabilities. A biofeedback system that could engage the subject by using interesting and entertaining feedback could increase compliance with exercises and could enhance the rehabilitation of persons with movement impairments.

The new system must be easy to use by both the clinicians and the patients. Clinicians should be able to quickly apply the system and initiate treatment with the system in less than 2 minutes. The new system must also be able to be used with patients with movement impairments from a variety of neuromuscular or musculoskeletal origins. In addition, the new system must be effective in engaging the patient to continue with their motor control and motor learning activities and exercises. The final requirement, is that the new system be as effective as existing biofeedback systems for the rehabilitation of persons with movement impairment.

DEVELOPMENT

The concept of the BioRehab System is the combination of EMG biofeedback with computer games. A prototype BioRehab System has been developed using EMG biofeedback and a PC. EMG signals are acquired from surface electrodes overlying the muscles of interest to the clinician. The feedback is provided via several different computer games selected for specific therapeutic goals. The PC based software "NeatTools" is the programming environment used to write the interface between the input from the EMG unit and the output to the PC games. A separate channel of EMG is required to control each direction of the mouse or cursor movement for playing the games. Within the BioRehab System software, each channel of EMG signal is optimized for screen display. The threshold level of EMG signal required for activating control of a cursor or mouse movement can be independently set for each channel.

EVALUATION

The clinicians and patients at the Advanced Rehabilitation Technology Center of the Sister Kenny Institute in Minneapolis, MN and at the Courage Center in Golden Valley, MN tested the prototype BioRehab System. Physical and occupational therapists responded to a written survey and oral interview. Questions included descriptions about the movement impairments and numbers of patient treated as well as both the clinician and patient opinions about the BioRehab System.

DISCUSSION

Fifteen clinicians and 100 patients used the BioRehab System during 6 months of clinical testing. The results of the survey and interview were generally positive. Clinicians liked the easy to use computer interface and the stable and consistent response of the BioRehab System. Clinicians reported that the BioRehab System could be set up and treatment begun within 3 minutes. Clinicians were successful in treating both upper and lower extremity movement impairments as well as impairments of the trunk. The clinicians also reported that patients of all ages liked the BioRehab System and enjoyed competing with the computer games. Patients reported that they were reluctant to end therapy sessions in which they were using the BioRehab System. Clinicians noted many functional improvements in patients including patients with chronic movement impairments who had been discontinued from traditional therapy programs for lack of progress. The clinicians reported that their patients were also able to identify positive carry over from the BioRehab System treatments to their activities of daily living.

Controlled and blinded clinical trials have been initiated.

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Development of a Patient Supporting Robot with Hydraulic Bilateral Servo Actuator

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ABSTRACT

One major difficulty in nursing the bedridden is lifting and carrying their body from one place to another, as well as changing their body posture. This work in an unstable posture usually causes the caregivers to suffer disorders of the body. We propose a solution by assisting this labor with robotic technology to lift a person's body with easy operation. The robot is designed with smooth, high torque hydraulic actuation and a bilateral servo system for the control to meet the necessity of the service. The superiority of this robotic device is in its interface and output torque. The bilateral servo system allows the robot to be directly operated (holding the end of the robot's arm) and to control the average weight of a Japanese adult (e.g. 60 kgf) with little effort (e.g. 1 kgf).

BACKGROUND

More and more families, especially in a society with increasing population of the elderly, are required to take care of their bedridden relatives at home. Caregivers are required to provide certain services, e.g. changing diapers and bathing, which involves heavy physical labor, in rooms that are not specially furnished for these services like medical facilities. Statistics in Japan indicate that the bedridden are under supervised care, on an average, approximately 8.3 months before passing away. This results in moving a heavy weight approximately 2000 times during these months. This situation becomes a major cause of backache and other disorders of the body, including mental stress to the caregivers.

One of the routines that cannot be reduced is treatment of the excreta. Changing diapers is usually performed by two caregivers in an unstable posture at the bedside, one lifting the patient's middle and lower body and the other cleaning the body and replacing the diapers. One cycle of this task takes 2 to 3 minutes minimum during which the body is held. A device for assisting in holding the body can ease this labor exceedingly.

Assisting devices have been developed with the aim of easing these kinds of body lifting requirements. Among these, assisting robotic systems are design to manage these tasks with intelligence and power. But many of these systems have deficiencies of being oversized and/or its operation being indirect, and critically lack a principle concept of safety.

RESEARCH QUESTION

The fundamental design requirements of a care assisting robotic system are compact size, sufficeint output power, and a plain direct operation. Safety features are also essential strategies that must be implemented. We defined the requirements of safety in the care assisting robotic system that has physical contact with human body as follow:

1. To maintain the current condition and complete the target task by switching to the reserve power supply when the main power goes down.

2. To complete the target task with the subject maintained in a safe condition, even when the cable is disconnected. It may be slow and less accurate, but it must finish all the required actions in the specified task to preclude risk of harm to the subject.

3. To pause temporarily by immediately shutting down the power when the system becomes seriously unresponsive, and ease in rebooting the system when the problem is solved.

4. To have protective cover around the robot body to prevent the robot from harming humans in the event of unexpected contact.

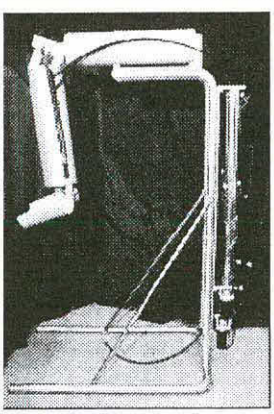
5. To possess a function and structure to prevent damage to and from its working environment.

The most difficult requirement in this table is to obtain a fail-safe actuator with the capability of holding a human body weight. We propose a new robot assistant with an actuator system designed for this purpose.

METHOD

In this research, hydraulic actuation is implemented due to its high output torque and smoothly connected movements. A bilateral servo system is implemented due to its advantages in fulfilling the requirements of direct robot operation. This system enables the caregiver to operate the robot arm by guiding it directly with their hand and without the need of preprogramming or keyboard input to control the trajectory as seen in industrial robots. This hydraulic system consists of a lightweight compact actuator, two simple cylinders in a master-slave relationship without requiring an external hydraulic power source.

A robot has been designed with this actuator system to reduce the heavy physical labor of diaper change. It is implemented on the bedside to hold the subject's body while the caregiver removes and replaces the diaper and cleans the body. The robotic arm is directly guided at its end with a single-hand action, even if it is already loaded with a heavy weight.



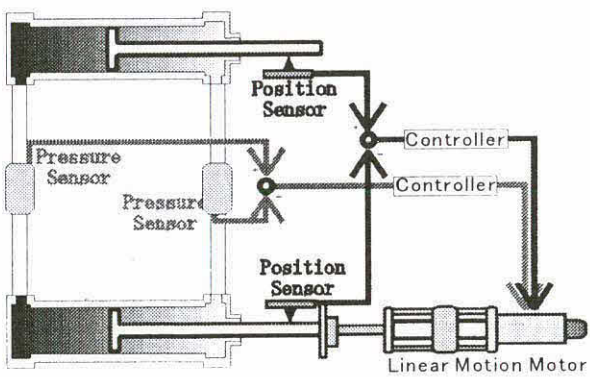


Fig.1. The care assisting robot with bilateral servo system (left)

Fig.2. The force transmission mechanism of the bilateral servo system (right)

RESULTS

The superiority of this system arises when it is controlled in an open loop. Fig.3. shows the repeatability characteristics of the system when 40 kgf of load is constantly given to the slave piston. The steady movement of the slave piston observed shows that it is controlled synchronously to the master without overshooting or vibrating, even when the system is not getting a feedback signal and the servomotor on the master cylinder is manually driven. This is an important factor that allows the system to be said to have a safe and tolerant operation with a wide range of stability.

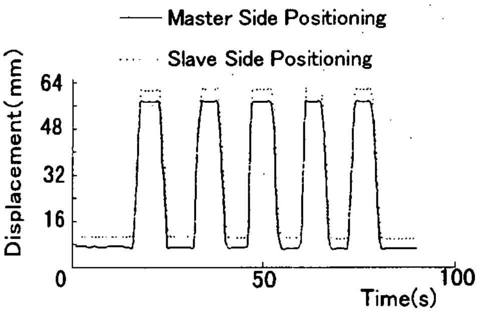


Fig.3. The repeatability characteristics of the system when 40 kgf of load is constantly given to the slave piston

DISCUSSION

An actuator with power sustaining Japanese average adult weight with friendly interface, relieving caregivers from special learning and training for robot operation, has been developed. Its appropriateness for use in human coexisting environments has been presented. The structure providing compact, safe, and high torque force transmission mechanism for the care-assisting robot has been described. As other applications of this actuator system, powered orthotic devices, bathing assisting robot, and externally powered lifter should be further developed.

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Development of a Microcomputer Controlled Electric Prosthetic Hand

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ABSTRACT

Demand for a lighter electric upper limb prosthesis requiring simple and low maintenance has been growing among Japanese users. The objective of this research is to develop a new prosthesis that meets the aesthetic and functional requirements of the electric upper limb prosthesis for the Japanese market. The technical challenge of this research is to develop gripping control architecture with a tactile control system and an appropriate outer covering for this sensor. A CAD/CAM system was applied for prototyping and producing the shell, inner glove, and cosmetic glove for the prosthesis.

BACKGROUND

The electric upper limb prosthesis was developed in the 1960's. After 30 years of research and development of this prosthesis, current usage rate is about 30% for upper-limb amputees in the U.S. and Europe. The rate is 8% in Japan, apparently low, and shows no sign of improvement. The causes for this situation are lack of acknowledgement by the public, delay in arranging social support policy for distribution, and lack of supporting facility with skills for secure distribution. Finally, there has not been sufficient effective discussion by the engineers to transfer technology to improve the prostheses.

Tokyo Denki Univ. is the only university continuously developing and clinically testing powered upper limb prostheses [1],[2],[3],[4]. Waseda Univ.[5], Osaka Electro- Communication Univ., and Hyogo Rehabilitation Center [6] are the very few other Japanese universities and institutes that has experience in designing powered upper limb prostheses. The WIME Hand, developed by Waseda University, is the only hand produced, marketed and presently in use. This hand is no longer manufactured. Except for imports, there is no off-the-shelf, reasonably priced national brand prosthesis. The claimed drawbacks of using the imported prosthesis are inconvenient maintenance service and burden in collecting information.

The foregoing argues the necessity of re-engineering prosthetic design to meet the need of potential users in the Japanese environment and produce and market the electric upper limb prosthesis.

RESEARCH QUESTION

The order of importance differs with the degree of amputation when listing the needs of the upper limb prosthesis. However, majors design criteria include weight, ease of wearing and operation, aesthetic appearance, and function. The deficiencies of the myoelectric upper limb prosthesis, when compared to the body-powered and cosmetic upper limb prosthesis, are prehensile function, weight, and ease of purchase and maintenance. From these criteria, we determine the required redesign specifications: lightweight design, improvement in prehensile function, and ease of maintenance.

Improving the prehensile function of the artificial hand is the technical challenge of the redesign. Improvement strategy is to realize non-voluntary actions and skin mechanism for human-like stable gripping and to develop a input method with limited command signals. Invoking a sequential automated action from a simple input is the advantage of installing a computer. Sensor(s) and a feedback control system assist the reflexive small actions. The aim of this research is to develop a compact computer controlled hand with a sensor feedback control with cosmetic coverings that is supportive of prehension.

METHOD

A new electric prosthetic hand is redesigned from TDU Hand ys-86[1]. The mechanism and materials are redesigned to improve the weight and maintenance problem. The control circuit has been totally redesigned using a single chip microcomputer for compact installation in the hand.

An on-off switch type tactile sensor and stable grip controlling system based on this sensor were developed. The mechanism of the tactile sensor was modified to improve the response characteristics and ease the maintenance over the sensors previously developed in the lab. Thirteen tactile sensors are mounted in a diamond pattern layout on the inner surface of the thumb. The algorithm analyzes the changes of the response condition of the sensors in the patterns. The motor is driven in proportion to the pattern changes. to flex the fingers and tighten the grip. The contact condition is an element of this tactile sensor. Therefore, the cosmetic and inner glove are designed and produced with consideration of the force transmission as well as the aesthetic function. The coverings are designed by 3D CAD for easy correction and reproduction. The aesthetic shapes are confirmed by producing models with rapid prototyping.

RESULTS

The weight of the mechanical assembly of the hand is approximately 230g, 0.1lbs., and is easily dissembled into 3 parts by unscrewing 2 to 3 bolts. The thumb and four fingers are layout consists of a 3-point clip. All digits are driven by a single DC motor through couplings. Springs are installed in the index and middle finger for adjusting the compliance.

The tactile sensor module consists of conductive rubber, coil spring, contact pin, terminals and plastic cases. The module is installed on the thumb phalanx plate with screws. A single tactile sensor is design to respond to 0.49N of load. The responding load can be adjusted by replacing the coil spring with different elasticity.

The Hitachi H8/3048 32 bit single chip microcomputer is used for the CPU. This processor controls the slippage detection gripping motion by driving the motor proportionally to the changes of the sensor patterns. This feedback control loop starts when first contact is made and ends at a command input to open the hand.

The system is designed to apply both electromyography sensor(s) and touch sensor(s). The electromyography sensor and the amplifier circuit have been developed for this prosthesis. The contact surface of the sensor is designed to reduce the errors when used in a sweating environment.

The cosmetic glove, inner glove, and shell are designed and prototypes are made with rapid prototyping.

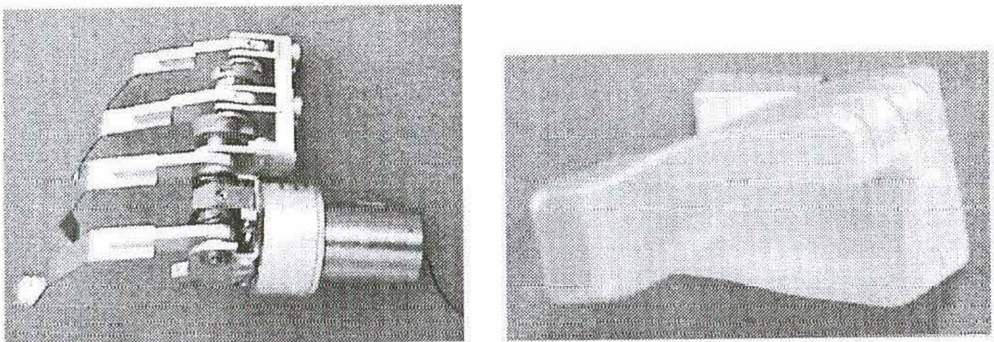

Fig. 1. Mechanical assembly of the prosthetic hand (left) and the shell (right)

DISCUSSION

The sensor feedback control of the digits effectively replaces the reflexive function of the hand. The local intelligence lowers the difficulty of adjusting to small changes in the gripping condition.

Rapid prototyping is used in designing the outer covering in this research. It produces effective result in modeling the outer shape of the hand. We believe CAE in mechanical design is especially effective to prostheses designs where smooth curve and surface and personalizing becomes a priority.

A series of prosthesis are to be developed for this project. Hand sizes and shapes differs by gender and age, therefore, we are to prepare 5 types of hand to satisfy a broad spectrum of users.

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WHEELCHAIR ATTACHED DESK FOR RYAN

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ABSTRACT

Ryan is a 16 year old male high school student who has been diagnosed with Duchenne Muscular Dystrophy. This disease has limited the mobility of Ryan's arms and legs, leading him to use a powered wheelchair during the school day. Desks and tables that are currently available to Ryan for writing and eating are not easily accessible from his chair. Other wheelchair desks on the market cannot be used due to mobility and wheelchair mounting restrictions, while custom desks through commercial suppliers were prohibitive in cost.

We have designed and built a retractable desk that Ryan is able to move into and out of position at will and without additional assistance. The desktop, made of transparent polycarbonate, is mounted to the back of his chair on two telescoping rails. A rotary gearmotor rotates the desk from its storage position behind the chair, over Ryan's head, and into place in front of him. Additionally, a linear actuator extends and retracts the telescoping rails in order to clear his head. Control switches attached to Ryan's armrests activate the motor and linear actuator, both of which run on the wheelchair's existing two 12 VDC batteries.

The entire assembly is self-contained on Ryan's wheelchair and does not exceed the chair's current width by more than two inches. This device will improve Ryan's independence, while making him more comfortable and productive throughout the day.

BACKGROUND

Ryan has been diagnosed with Duchenne Muscular Dystrophy (DMD), which is characterized by the progressive weakening and deterioration of muscles. Over the past couple years, Ryan has lost considerable strength in his legs and arms. Because of this, he spends his days in a motorized wheelchair. Ryan has a very difficult time performing any motion against gravity, which is most evident in his inability to raise his arms to any appreciable degree. Because Ryan cannot extend his arms very far he is forced to lean far forward to reach tables and desks that his wheelchair cannot fit under. In some instances, he is forced to work off of his lap, which causes him to place further strain on his back and neck. There are several products on the market designed to address similar problems, but they have not been useful for Ryan. Most of these desks sit on the floor and then require a third party to set the desk in place, remove it, and transport it to other classrooms. Other desks designed to mount on the chair itself cannot be used because of Ryan's sophisticated and crowded wheelchair. Neither of these can be brought into or out of position without the assistance of a third party.

DESIGN

After consulting with Ryan, his family, and his therapists, we determined that Ryan would greatly benefit from an automated desk attached to his wheelchair. The main objectives were that the desk be able to support up to 10 pounds of books, be transparent so that Ryan could see in front of him while the desk was in place, provide support for his elbows, be mobile with the chair, and allow Ryan to retract the desk by himself when not in use. However, due to Ryan's sophisticated wheelchair, there were also several restrictions. The entire assembly could not exceed the width of Ryan's chair by more than two inches. Otherwise, he would be unable to fit through most doorways. Any motorized parts were to get their power supply from the two 12V batteries that already run the chair. Because Ryan often adjusts his position in the chair by tilting or reclining to relieve pressure points, there were few fixed mounting points. Almost all of the possible mounting points move relative to each other, requiring mounting be made to a single piece of the chair.

With those objectives and constraints in mind, we decided to design a desk that stores behind Ryan's chair and swings into place over his head. When activated, it rotates from behind the wheelchair, over Ryan's head, and down onto the armrests in front of him. Retraction of the desk takes place in reverse along the same path. In order to gain enough clearance over Ryan's head, the desk sits on two telescoping rails (one on either side of the chair) which extend as the desk rotates above him. A 12VDC permanent magnet gearmotor, mounted to the back support on the left side of his chair, is responsible for rotating the desk over Ryan's head.

The extension and retraction of the desk along the telescoping rails is accomplished using a 24VDC linear actuator. The actuator is mounted at a single, pivoting point on the back support on the right side of the chair so that it rotates with the desk. The telescoping rails consist of three separate pieces that slide together on ball bearings. The inner rail can be removed from the rest of the pieces by disengaging a plastic clip. Our desktop is exclusively attached to these inner pieces, which means that removal of both inner rails allows the entire desktop to be removed as a unit. This provides a method to quickly remove the desk when it is in place in front of Ryan, in the case of an emergency.

The desktop itself is made out of a clear polycarbonate material. It is equipped with a cutout for Ryan's motion joystick (allowing him to move his chair while the desk is in place), a groove along the perimeter of the surface to prevent pencils from rolling off, and rubberized elbow rests to cushion his elbows and keep them from slipping off of the desktop. Since the motor responsible for rotating the assembly is only directly attached to one of the rails, the desk is the only means by which the other rail (connected to the actuator) can be swung around. The desk itself is not strong enough to bear this twisting load, so a desk reinforcing bracket was designed to facilitate the rotation of the opposing arm. This bracket, which is made of 1/2 inch thick steel tubing, also helped to prevent any buckling of the desk due to heavy books or the weight of Ryan resting on his elbows.

Although the final design is functional at this time, a number of safety and positioning concerns still need to be addressed before the device can be delivered. First of all, the current speed of the gearmotor is too fast to allow for very precise control of the desk angle. A DC motor control will be used to slow the motor speed. In order to guarantee that the desk will never fall from a raised position when the power fails, we plan to add a motor brake that releases only when the controls are activated.

Another major safety concern is the possibility of the rotating pieces pinning something against the armrest. Contact strip switches along the rails will serve to cut power to the motor (in the direction of rotation) if the switch is contacted. Feedback circuitry will also be added to prevent the possibility of the desk hitting Ryan's head or chair during rotation. This will indicate the position of the desk so that if the actuator is not extended, the gearmotor would not be permitted to rotate towards Ryan. The feedback circuitry will also be useful in ensuring that the desk does not hit the floor when Ryan reclines.

Finally, we need to design and mount the control switches. There will be two switches mounted near the armrest by Velcro. This will allow the controls to be moved so that they are still accessible by Ryan when the desk in place. One of the switches will simply move the desk into and out of place, utilizing the feedback circuitry to extend and retract the actuator at the correct time and removing the need for Ryan to control motions he can't see. A separate switch will be used to control the actuator when the desk is in front of Ryan. The switches will actually be relays, isolating Ryan from the battery voltage. All of these issues will be addressed in the coming Spring semester.

IMPACT

Ryan is a highly motivated young man who is doing everything possible to not let his disease get the best of him. However, his current inability to comfortably use a desk or table at school prevents him from maximizing his academic potential. In addition to the discomfort, working out of his lap or at awkward angles places harmful stress on his shoulders and upper back. We believe that Ryan's ability to transport his desk on his chair and to move it into and out of position by himself, will greatly increase his independence. He will be able to use this desk for his school work and reading, laptop computer, and for playing video games. Ryan's occupational therapist had the following quote regarding our project:

"This project fulfills a need that Ryan has had for about a year. He has struggled with the fact that he has had to spend more time in a wheelchair and that aspects of his school environment, such as desks, are not fully accessible to him. This wheelchair attached desk decreases his dependence on others to modify the environment for him, allowing him retrieve, or only have to ask for items to be placed on his desk. This allows him to get at school related tasks faster. He can once again move about carrying items with greater weight than what he was able to manage on his lap."

SUMMARY

Our extensive research throughout the design and construction of this desk brought the unfortunate reality of health care products to our attention. Specialty devices, such as the desk that we built for Ryan, are not available because companies need to customize such devices to each patient's specific needs, and a profit would not be possible unless an extreme price was charged. Knowing that there was nothing commercially available to help Ryan made this project even more meaningful, since we realized that our efforts were addressing a very important need that was being neglected.

We have designed and constructed a mechanically sound automated desk for Ryan's wheelchair. The controls have been designed such that Ryan can bring the desk into and out of position with relative ease. This will increase his independence and allow him to complete his school work and other desk intensive activities more efficiently and without physical harm. We have met all of Ryan's personal design requirements, while conforming to the constraints that the wheelchair imposed on our design.

This project has been tested for proper operation and mechanical sturdiness, but safety concerns must still be addressed next semester. Solutions for all of our safety concerns have been developed, but time restrictions for this semester have been the only limiting factor in their physical realization. Experts in product safety and ergonomics will also be consulted for feedback throughout the finalization process. This entire procedure will conclude with a final delivery of this project to Ryan and his family by the end of next semester.

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INSOLE GYRO SYSTEM FOR GAIT ANALYSIS

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ABSTRACT

The use of a miniature solid-state gyro sensor, mounted in a shoe insole, was investigated to determine whether it could be used to record ankle joint velocity during the push-off phase of gait. Foot and ankle angular velocities were simultaneously recorded by the gyro sensor while a subject underwent a standard 3D video-based gait analysis. The gyro signal tracked the angular velocity of the foot segment well. Whilst there were discrepancies between the gyro signal and ankle velocity during the swing phase, in the stance phase they were tightly correlated. An insole gyro thus offers potential for estimating the ankle velocity during the push-off power-generation phase of gait.

BACKGROUND

Computerized Gait Analysis, using video-based techniques, has provided useful insights into the biomechanical cause of gait abnormalities. One very common finding in a variety of clinical disorders is a reduction in ankle power at push-off (1). This power burst (A2) is chiefly responsible for the propulsion of the leg into its swing phase, and is thus highly correlated with the length of stride (2). A reduction in A2 power is therefore usually accompanied by a shortened stride, giving rise to decreased walking velocity and disability (3).

Recently, the advent of miniature solid-state gyro technology has provided a simple and accurate method for measuring velocity of limb segments during gait (4). This study investigated the possible use of such sensors for estimating ankle velocity during push-off with a view to measuring ankle push-off power by combination with insole force sensors.

RESEARCH QUESTION

The objective of this study was to compare the output of a gyro sensor mounted in an insole with the angular velocity of the foot and ankle as measured by a 3D gait analysis system. Of particular interest was the correlation between gyro and ankle velocity during push-off.

METHOD

The solid-state gyro sensor (Type ENC-03JA, Murata, Japan) was mounted in a Pelite insole (fig. 1). Its location in the instep was selected so as to be unaffected by flexing of the sole, and it was aligned transversely, such that it was most sensitive to angular velocity about the talo-crural joint.

The subject then underwent a standard 3D gait analysis, using a Vicon motion analysis system (Oxford Metrics, Oxford, UK). The *Vicon Clinical Manager* (VCM) model (5) was used, with markers on the second metatarsal, lateral malleolus and lateral femoral condyle determining the foot and ankle joint angles. The output of the gyro sensor was recorded simultaneously. The subject was asked to walk slowly (0.65 m/s), in order to simulate a pathological gait. Several steps were recorded.

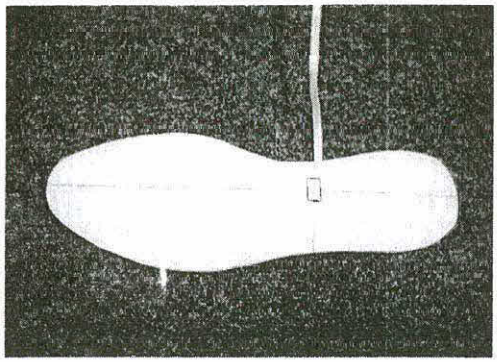

Fig. 1: instrumented insole, showing gyro sensor.

RESULTS

The output of the gyro sensor closely tracked the angular velocity of the foot, as measured by the *Vicon* motion analysis system (fig. 2). When compared with the ankle joint velocity, there were large discrepancies during swing phase. However, during stance phase, and particularly during the push-off power-generating phase, the gyro signal was very well correlated with ankle velocity (fig 3).

A linear regression between the gyro signal and the ankle angular velocity during the push-off phases (fig. 4) revealed a correlation (r^2) of 0.93.

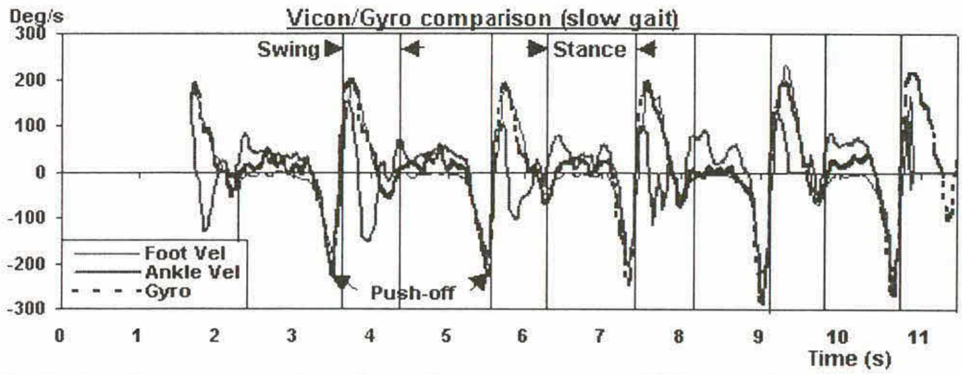

Fig. 2: simultaneous recordings from the gyro sensor and Vicon gait analysis system.

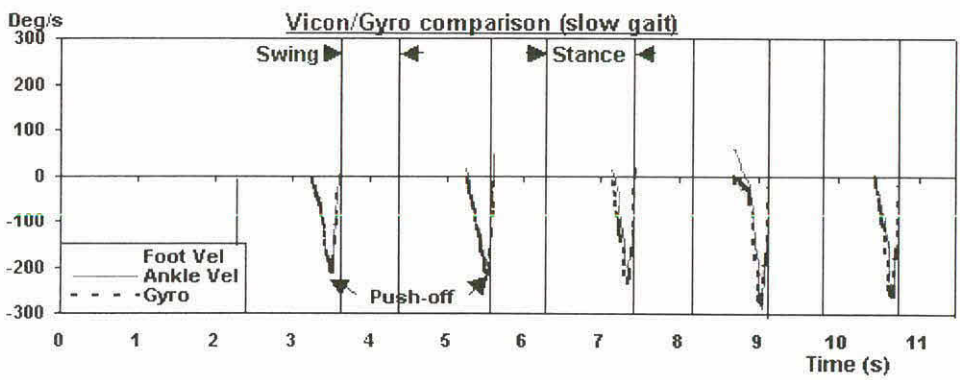

Fig. 3: push-off phases – note good correlation between the gyro signal and ankle velocity

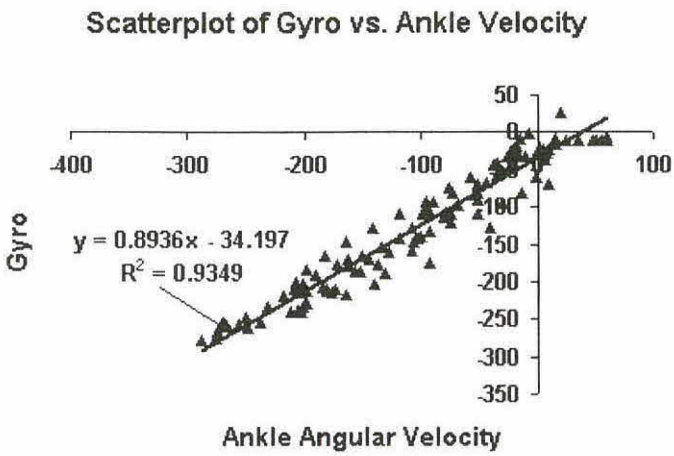

Fig. 4: correlation between the gyro signal and the ankle velocity during push-off phases.

DISCUSSION

Solid-state gyro sensors offer several advantages for use in rehabilitation engineering. They are small, resilient, relatively cheap, and require very little additional electronic componentry (merely a 3V power supply). They are thus eminently suitable for mounting inside the shoe. This study has shown that such an arrangement can provide very useful information concerning the angular velocity of foot and ankle during the important push-off phase of gait.

The information obtained could be used in several ways. Firstly, the cyclical velocity spikes could be used to detect and count steps, and calculate cadence. When combined with a miniature force sensor, also mounted in the insole, it may also be possible to estimate power generation during the important push-off phase. This would provide a simple clinical tool with which to quantify gait performance and diagnose disorders in which push-off is reduced.

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A BIOMECHANICAL MODEL OF THE SPINE AND TRUNK FOR SIMULATION AND CONTROL OF POSTURE AND BALANCE

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ABSTRACT

A computational model of the kinematics of the spine and the force-generating capacity of the major muscles of the trunk was constructed to understand their role in the maintenance of seated or standing posture and balance. Vertebrae and ribs from a physical specimen were digitized and scaled to represent average proportions. Origins, insertions and moment arms of the *erector spinae*, *quadratus lumborum* and *rectus abdominus* were determined and found to be in good agreement with values reported in the literature. Movement of the spine was constrained to distribute motions realistically across the appropriate spinal levels. Measurements of muscle architecture were obtained from six fresh-frozen cadaver specimens to estimate the parameters of a Hill-type model for predicting force-generating capacity. The resulting parameters were pooled and used to compute the flexion, bending and rotational moments of the torso in response to activation of the trunk muscles. These estimates are being compared to experimental measurements of isometric moments produced by electrical stimulation in individuals paralyzed by spinal cord injuries (SCI). This new tool may be particularly useful for simulating the actions of functional neuromuscular stimulation (FNS) on individuals with SCI, or to predict the outcome of various seating systems or surgical interventions.

BACKGROUND

Controlling the mass of the trunk is critical to erect posture and the maintenance of seated or standing balance. To understand the biomechanics of postural regulation, many researchers have constructed simple planar models of the body that tend to group the inertial properties of the head, arms and trunk into one rigid segment attached to the pelvis. Such simplification ignores the roles of both the upper extremities and bending movements of the trunk in maintaining balance. In particular, individuals paralyzed by spinal cord injuries often develop deformities from prolonged sitting in sub-optimal postures due to the absence of active trunk muscles. Standing is possible for individuals with SCI using braces or FNS, but systematic and dynamic control of the trunk is lacking. The trunk can be braced in a TLSO or with continuous stimulation to the paraspinal muscles, effectively making the complex mechanism of the spine a single unit, thus eliminating its ability to make postural corrections necessary to maintain balance or to perform a variety of activities of daily living. Inability to control the trunk contributes to the necessity to rely on the arms for support and balance while standing, thus reducing the functionality of FNS or braces by compromising the ability to work or manipulate objects in the environment. The objective of this study was to measure directly the key anatomical parameters of the prime movers of the trunk accessible to electrical stimulation. These measurements were then used to develop a computational model of the torso that can predict the effects of electrical stimulation to test various control strategies in simulation. The model is also intended to be used to simulate seated postures and the activity of the trunk during reaching or other work-related upper extremity activities performed from the wheelchair.

RESEARCH QUESTIONS

Can an anatomically realistic representation of spine kinematics and static moment generating capacities of the major trunk muscles be constructed? Does the computational model predict the moments produced by the trunk extensors with electrical stimulation in volunteers with SCI?

METHODS

A computer model of the bony structure and musculature of the trunk was constructed using Software for Interactive Musculoskeletal Modeling (SIMM, Musculographics Inc.).[1] Vertebrae and rib surfaces from a physical specimen were digitized and scaled to represent average proportions. Initial estimates of the origins and insertions of the three muscle groups primarily responsible for trunk motion and routinely accessible to electrical stimulation - the *erector spinae* (iliocostalis lumborum, logissimus thoracis and spinalis components), *quadratus lumborum* and *rectus abdominus* - were determined from anatomical measurements and CT/MR images and incorporated into the SIMM model of the trunk. The moment arms of the resulting muscle representations were computed and compared to reports published in the literature.

Relative motion of the spine was derived from data reported by Panjabi and White.[2] Flexion-extension occurs primarily at the lumbar region, axial rotation over thoracic levels, and lateral bending is distributed relatively evenly across all vertebrae. Movement was distributed along the spine in proportion to the relative contributions described by these relationships, thus tightly coupling the motions of the individual vertebrae. These kinematic constraints can be easily modified to represent range of motion limitations (fixation or spinal fusion), deformities (lumbar lordosis) or other patient-specific characteristics.

Measurements of muscle architecture were obtained from six cadaver specimens to estimate the parameter values for the Hill-type model used to predict their force generating capacities. The resulting architectural parameters were pooled to construct the final computational model. Musculotendon length, muscle length, fascicle length, pennation angle, sarcomere length and muscle mass were measured for each specimen using microdissection and laser diffraction techniques.[3] From these parameters, physiological cross-sectional areas (PCSA) and optimal fiber lengths were derived.

Active isometric trunk extension moment was measured using a Biodex Pro System 3 dynamometer at different points throughout the range of motion on two subjects with complete mid-thoracic SCI. Volunteers had intramuscular stimulating electrodes inserted into the vertebral foramen at either T12-L1 or L1-L2 to excite the spinal roots that innervate the iliocostalis lumborum or longissimus thoracis for trunk extension during standing with an implanted FNS system. A 20 mA, 30 Hz biphasic charge balanced stimulus was applied repeatedly to electrodes individually and simultaneously in random order at a duty cycle sufficient to avoid fatigue. Stimulus pulse durations were adjusted to yield maximal activation without spillover to undesired muscles. The experimental measurements were then compared to the predictions of the trunk model

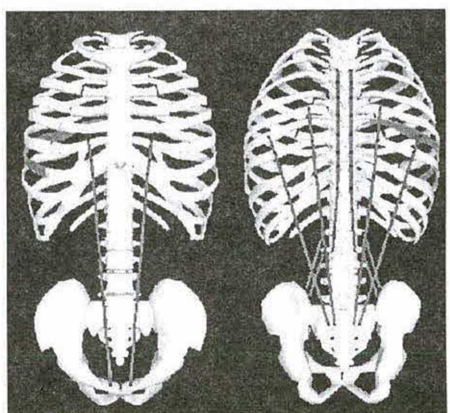

Figure 1: Anterior and posterior views of the trunk model showing rectus abdominus, quadratus lumborum and erector spinae.

RESULTS

The moment arms of the muscles with the model in the sagittal plane at each vertebral level while in a neutral spine posture were found to be in good agreement with values reported in the literature.[4,5,6,7] Similarly, vertebral dimensions and stature were within one standard deviation of the 50th percentile proportions of able-bodied males.[8,9,10,11]

Final values of the muscle architecture model parameters were consistent across all six specimens. The mechanical relationships of the muscles to the skeleton have been finalized, and the predictions of static flexion, bending and rotational moments of the torso in response to the forces produced by them are reasonable and within physiological ranges. The resulting 3D model of the human trunk is illustrated in **Figure 1**.

Values of unilateral isometric trunk extension moment predicted by the model for two columns of the erector spinae and typical experimental measurements from stimulation of the lumbar roots are shown in **Figure 2**. The isometric moment-angle curves elicited by electrical stimulation maintain the same shape as predicted from the simulation, although they are reduced somewhat in magnitude. This result was consistent for both subjects and all electrodes.

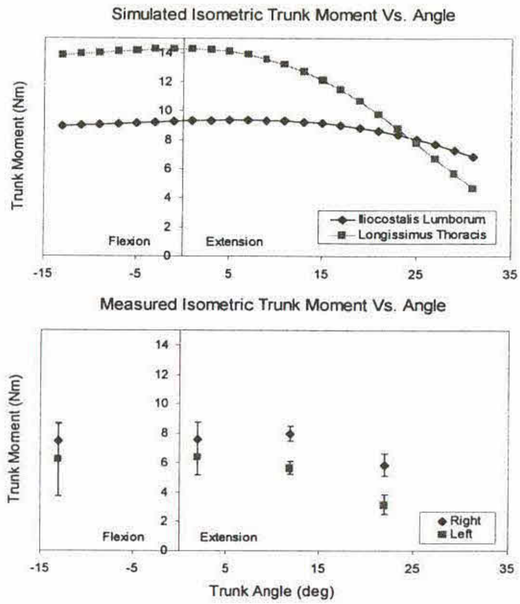

Figure 2: Predicted (top) and experimental (bottom) isometric trunk moments from SIMM model and stimulation of the erector spinae.

DISCUSSION

A new model of the human trunk based on the anatomy of able-bodied cadaver specimens and scaled to average stature was constructed. The model captures the salient features of the kinematics and static moment-generating capacity of the trunk muscles. Differences between predicted and measured moment values could be due to changes to muscle properties (i.e., PCSA) after SCI and to inability of a single electrode to fully recruit all fibers of the segmentally innervated erector spinae. Further development and testing is required to establish the accuracy of the model, adapt it for SCI, and perform dynamic simulations before its true value as an analytical tool for studies of seated or standing posture and balance can be fully determined.

ACKNOWLEDGEMENTS – Support for this project was provided by the Neural Prosthesis Program of the National Institutes of Health, Contract N01-NS-6-2351.

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DESIGN OF A CUSTOM WEIGHTLIFTING ORTHOSIS FOR A PERSON WITH TETRAPLEGIA

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ABSTRACT

The purpose of the project was to increase a client's independence during his weightlifting workouts. Orthoses were designed to eliminate three identified barriers the client was experiencing during weightlifting activities. He is now able to independently workout after someone removes the weight from the rack and places it on a weight bench. The orthoses were designed and tested with him in his wheelchair thus taking into consideration any potential wheelchair interference. Finally, the orthoses were universally designed for weights used at most weightlifting centers. The client now has the freedom to visit other locations near his home and while traveling.

BACKGROUND AND RATIONALE

This case study involved a client who had been regularly lifting weights, but was unable to increase the amount he was lifting due to certain barriers. The client was a 37-year-old male with C7-8 complete tetraplegia as a consequence of a motor vehicle accident in 1982. He was covered under the State of Michigan No-Fault insurance system. He had good biceps control with decreased triceps and hand strength. He used a manual wheelchair for independent mobility.

Three years ago he hired a personal trainer to assist him in proper weight training. His program required adaptive configurations for weightlifting activities including biceps-curl and lattisimus dorsi pull-down exercises. Wrap-around weights were placed around his forearm for biceps-curl exercises. Gloves with loops attached to the backside of the wrist were used when the client performed pull-down exercises on weight machines. The client believed a better method could be developed. As a result of this belief, he referred himself to the University of Michigan Rehabilitation Engineering Program.

DESIGN CRITERIA

The goal was to find an alternative method of performing the desired weightlifting tasks that did not limit the amount of weight desired to be lifted, reduced the amount of assistance needed to perform the exercise, allowed for a greater range of weightlifting systems to be utilized, and eliminated contact with his wheelchair while lifting.

DESIGN PROCESS

Commercial Products. An initial meeting between Rehabilitation Engineering staff and the client was used to discuss his goals, identify potential off-the-shelf solutions, and develop a plan regarding how to proceed. This meeting resulted in a product search for a robust glove-type system and a plan to develop a multi-disciplinary team. An occupational therapist, was contacted to provide design input, and to assist in locating commercially available products. Commercially available products did not meet the requirements of the client. Product searches resulted in a lack of options that had the ability to support the amount of weight the client has the potential to lift. The only

comparable device that could be found did not have the ability support the amount of weight the client desired to use (1). Therefore there was a need to find an alternative solution.

Custom Product. A second meeting with the client resulted in a list of design ideas. During this session a wrist brace with palmer and dorsal support in combination with a leather glove having a Velcro attachment to hold a weight was fitted over his hand to simulate a possible solution. This simulation only worked for weights under five pounds. However, the idea of the design appealed to the client. At this point, a more universal design concept was considered to provide access to a potentially greater range of weightlifting systems.

A strong, lightweight material, with good support, was required to withstand the high forces associated with the amount of weight the client wished to lift. The specialized material and individual fitting required for the design of an appropriate orthosis warranted bringing an orthotist and orthotic technician onto the team. A meeting was held with all rehabilitation team members and the client to provide him input opportunity in the refinement of the design for a weightlifting glove. The concept of a locking mechanism was discussed that would: provide stability, lock the weight in place, and be independently operated by the client. During this meeting the design of a weightlifting glove was determined and it was decided to build a prototype. The fabrication of the right-hand orthosis was as follows:

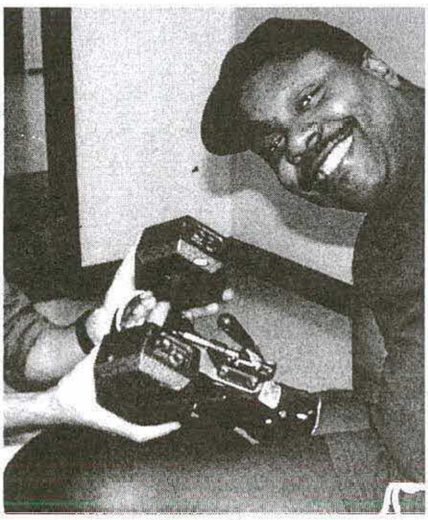
Figure 1

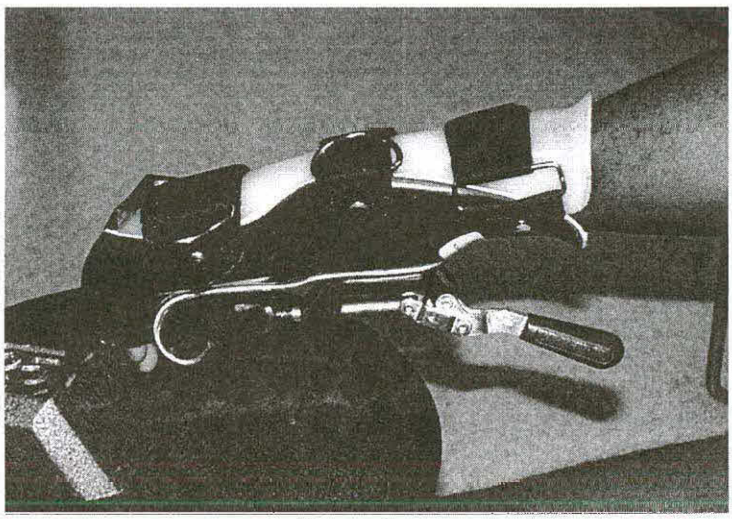
Figure 2

FABRICATION PROCESS

A prototype of the orthosis was made for the right hand of the client by taking a mold of it and the forearm using 3M Softcast, a semi-rigid form of fiberglass. The hand was positioned in slight wrist extension and ulnar deviation to mimic the position of function during weightlifting. The thumb was also positioned in slight retropulsion. This positive cast was modified to support the specifics of the orthosis design. The final orthosis laminated. It included a modified plunger lock mounted on the palmer side used to lock the free weight into position during biceps-curl exercises, (figure 1). The dorsal aspect of the orthosis had a riveted polyethylene tongue secured with overlapping D-ring Velcro straps, (figure 2).

Several fitting sessions were held to modify the orthosis to ensure total contact was achieved. The total contact design principal decreases the propensity for excess pressure and shear forces during activity. The client tested the right orthosis for a two-week trial period. This trial period proved successful with only minor adjustments made to it for comfort prior to beginning fabrication of the left orthosis.

EVALUATION

The client was extremely pleased with the weightlifting orthoses. In later follow-ups, the client commented on the positive aspects of them. He made several observations: his independence had increased, only initial set-up of the weight and the pull-down exercise was required, and the weight no longer came into contact with his wheelchair. Also, the orthoses could be used with free weights in other locations such as hotel workout rooms while traveling. One enhancement offered by our client was to "streamline" or minimize the size of the plunger lock to decrease the weight and improve the sleekness of the orthoses.

DISCUSSION

The solution to this problem addressed two important points. First, the independence of the client greatly increased. Minimal set-up for the free weights was required (i.e. moving the weights from a standard rack to a bench) for biceps-curl exercises. For lattisimus dorsi pull-down exercises initial placement of his hands on the bar was needed. Second, the orthoses were designed for universal use. The orthoses were successfully used with the originally identified equipment and have the potential to provide access to additional pieces of equipment if the client chooses to expand his workout routine.

It is worth noting that a team approach including the expertise of the client, rehabilitation engineers, an occupational therapist, an orthotist, and an orthotic technician was needed to solve the problem. Without the varied expertise that each team member offered, the final product would probably not have been as successful.

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ACKNOWLEDGMENTS

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A CARBON COMPOSITE GAIT ORTHOSIS TO IMPROVE GAIT AND STABILITY IN PATIENTS WITH FOOTDROP

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ABSTRACT

There are available a wide variety of ankle foot orthoses for stabilizing the ankle and the foot. The main indication is to prevent footdrop, commonly seen in C.V.A. patients and other types of neurological disorders. The compliance of these orthoses has not in many cases been acceptable. Some reasons for this are the clumsiness and heaviness of the brace, discomfort at the heel, and difficulties in wearing the orthosis in conventional shoes. Furthermore, the gait when wearing the braces has been improved only to a small extent. The toe off of the forefoot during the gait is not dynamic and the stance and swing of the foot are rigid. This paper will present a review of the materials used in development of a new Composite Rehabilitation Gait Orthosis, and a Vicon gait analysis study of a patient comparing "normal" gait patterns to gait patterns when wearing a conventional AFO and then wearing ToeOFF.

BACKGROUND

A typical cause for drop foot is peroneal palsy, which results in instability in the knee and ankle joints. The loss of ankle dorsiflexion demands more lift of the foot resulting in more knee and hip flexion. The gait pattern automatically changes, which impacts the velocity, the stride length, the cadence and the single Support Time. These 4 elements are of vital importance for the walking capacity or the mobility of our patients and were therefore subjects for the studies we performed.

DESCRIPTION OF A NEW DESIGN

Numerous concepts, shapes, trim lines and compositions with fibres like Carbon, Glass, Dynema and Kevlar were tested, before the final concept was recognized as the ToeOFF product. The composed hybrid is capable of performing in the way we feel needed, better than any other material.

The goal was and still is to achieve a closer to "normal" gait pattern with the best possible cosmesis. This demands a dynamic orthosis, which requires a hybrid composition. Some parts of the orthosis should follow the contours of the body. Glass fibre was selected to offer this flexibility. The rigidity and the recoil effect were established with a combination of Glass, Carbon and Kevlar. The Kevlar is known for its tensile strength and is therefore used in the core of the sole.

The combination of Glass and a matrix of epoxy results in a great flexibility, which was used for the wings to enhance comfort and fit. To provide required support, the anterior tibial plate must be rigid so carbon fibre was selected for this purpose.

The anterior tibial plate and the unilateral strut were also chosen to avoid pressure on sensitive areas such as the Achilles tendon. In addition, the counter pressure for the recoil effect is best transferred to the skeleton by the wide anterior surface in order to reduce excessive pressure on the soft tissue. The sole has a mild average shape, which fits nicely in the shoe.

A CARBON COMPOSITE GAIT ORTHOSIS

The weight of this hybrid structure measures only 100 gram (approx. 3,5 ounces). Together with the thinness a great contribution for patients with neurological disorders

The standard product will already improve the dynamics of the gait. Adjustments can be performed on the shape and size of the sole by cutting and grinding. Paddings can be added to the sole to restore the arches.

The tibial plate can be individually padded by foam leaving a channel to prevent pressure on the tibial crest. As a closure pile and loop is most suitable. Depending on the function of the hands the closure could be adapted by leaving out the loops. In that case both wings will be furnished with pre-glued hook closure.

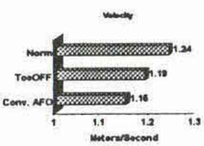
To protect the shoe from chafing against the strut and the edges of the sole; the strut and sole can be covered with leather. This way the moving strut will no longer harm the shaft of the shoe.

VICON GAIT ANALYSIS STUDY

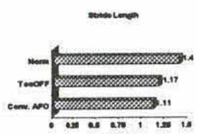
A gait analysis study was performed using the Vicon system of the Gait Laboratory at the University at Lund in Sweden.

The patient has paralysis of the Triceps Surae muscle; he wore, as usual, markers on his hip, knee, ankle and forefoot. In this study a comparison was made while wearing shoes only followed by wearing a conventional AFO and by wearing ToeOFF.

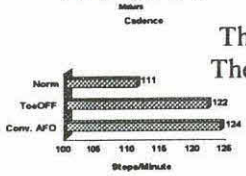
The overall results of this study were: "A more dynamic gait with less limp, decreased drop foot and increased knee and hip flexion. The patient could walk longer distances because of increased stride and improved single support time.



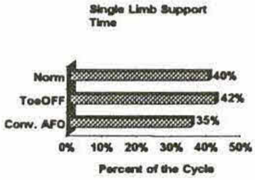
When examining the velocity the results were compared with the velocity of normal test persons, which was 1.24 meters per second. With a conventional AFO the patient could reach 1.15 meter per second and with the ToeOFF a velocity of 1.19 meter could be reached.



The stride length of a normal test person is one meter 40. Our patient could do one meter 11 with a conventional AFO and reached one meter 17 with the ToeOFF.



The cadence was registered as follows. The test person only needed 112 steps. The patient with a conventional AFO used 124 steps, while the same patient with the ToeOFF used 122 steps. It may be obvious that the normal test person can take longer strides, which means he would need fewer steps to walk a certain distance.



Even more interesting is the single support time; it can be noticed that the patient can keep his body weight longer on the affected side; which in this case is the ToeOFF. As a result the limb is less evident or does not even exist anymore.

SUMMARY

The overview of the gait lab results show that the Cadence, Velocity, Stride Length and Single Support Time were closer to normal when wearing ToeOFF versus a conventional AFO. These results were possible due to the dynamic toe-lift effect and the lightweight design.

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A UNILATERAL-PHYSICAL-SAGITTAL KNEE BRACE FOR ORTHOTIC MANAGEMENT OF OSTEOARTHRITIS

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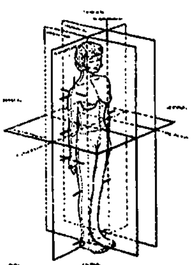
ABSTRACT

Prefabricated knee orthoses generally offer flexion and extension control. Knee alignment correction in the frontal plane, however, requires a different design. If besides flexion, adjustment by the sagittal axes is needed to unload the medial or lateral compartment, joints and frame need different functions. A unilateral joint can be aligned more easily than bilateral joints and offers improved cosmesis. The movement of the joint should imitate natural knee movement to prevent unnecessary friction between the articulating joint surfaces. The thigh and shin cuffs divide pressure to maintain alignment of the extremity. Biomechanics of the knee joint limits knee alignment changes from ±20° flexion until full extension—which will be sufficient for unloading. Although the biomechanical result of valgus or varus knee braces for management of osteoarthritis remains to be scientifically proven, a great number of cases have reported reduced pain and longer retention of knee joint mobility.

BACKGROUND

Prefabricated knee orthoses are generally designed to stabilize frontal axis movements. Usually, they can offer flexion and extension control. If, however, knee alignment correction in the frontal plane is required, a totally different design or a custom brace is demanded. If besides flexion, adjustment by the sagittal axes is needed to unload the medial or lateral compartment, joints and frame need different functions. The use of a second joint becomes difficult when the uprights are to be changed to accommodate for valgus or varus; because the length of the opposite upright has to vary when changing the position. A unilateral joint can be aligned far more easily and offers improved cosmesis. To minimize pain and protect the osteoarthritis knee joint, the movement of the joint should imitate natural knee movement to prevent unnecessary friction between the articulating joint surfaces. The thigh and shin cuffs must divide proper pressure to maintain alignment of the extremity without undue discomfort for the patient.

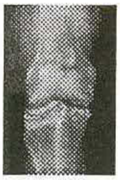


A number of studies have validated that unloader knee braces can improve the alignment of the knee, reduce pain, extend walking distance, and extend retention of knee joint mobility. When talking to arthritis patients, their primary concerns are "comfort" and their ability to function. Just fixating the leg in their neutral position can result in a positive effect, provided the new situation is comfortable for the wearer. When this stage is reached, just a few degrees adjustment into valgus or varus will unload the medial- or lateral compartment, thus protecting the joint from further degeneration by the applied loads. A comfortable brace, limits pressure build up to a minimum, should be light, cool to wear and easy to doff and done. For the orthotist, there are some more important aspects for successful bracing like avoiding friction and how to improve function and cosmesis. The user would look at cosmesis through other eyes of course; they worry more about: "How do my friends and neighbors look upon me with a brace on; will it fit in my trousers and can it be cleaned easy enough?"

A UNILATERAL-PHYSICAL-SAGITTAL KNEE BRACE

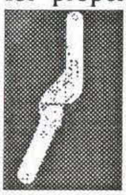
DESCRIPTION OF A NEW DESIGN

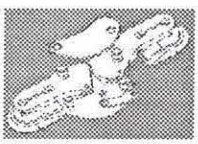
I will now present to you design elements I have incorporated to offer a prefabricated knee orthosis to address these issues and functions.



Osteoarthritis knees are often swollen sensitive knees. Pain in the affected knee and the incongruity of the joint surfaces make the use of muscle traction for active correction a painful experience. For this reason, we have to avoid friction when guiding the knee into flexion and extension. To minimize this friction, we have constructed a four-axis joint, which simulates the movements of the natural joint most closely.

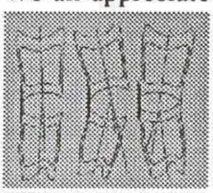
We have mentioned earlier that maintaining the leg in a neutral and comfortable position is already a benefit, the few degrees of correction will establish the result for the future. The condyles of the femur and tibia head can be identified on the brace; the simulated tibial plateau can be used to check for proper alignment on the leg. The diagram shows the moving axis from flexion into full extension. A positive effect of the joint properties is the soft braking effect before reaching extension. The placement of the four axes will slow down the movement, resulting in a soft stop. In full extension a "natural lock" can be experienced, which allows unlocking when action is initiated by the lower leg. The joint will allow a range of motion of approximately 140°, which is sufficient for normal function.





The joint incorporates a triple layer construction to control the extreme high lateral forces and to assure smooth function at the same time. Thanks to the air space industry, we were able to choose a fine alloy of aluminum for the uprights, which has a tensile strength tenfold higher than the usual aluminum alloys.

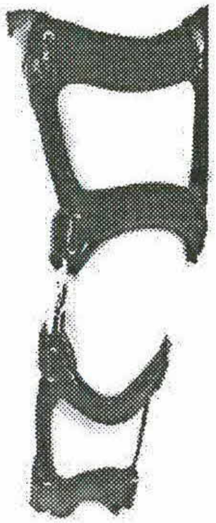
We all appreciate how difficult it can be to keep joints parallel in all planes, while being able to conveniently change position of the cuffs. With this unilateral construction, we can virtually keep the joint in line with proper function of the knee while allowing corrective forces at the same time. To achieve this, the adjustment fixtures laminated in the cuffs will each allow for 25° range of motion around the sagittal axis. This results in a total range of motion – from extreme valgus into extreme varus – of approximately 50°.



Biomechanics of the knee joint limits knee alignment changes only from ±20° of flexion until full extension – which is sufficient for unloading the knee joint. Since the required function is mainly a correction into valgus, we preferred a lateral joint; thus keeping optimal space in between the knees for improved walking ability. In quite a number of cases, both knees are affected, which means that "two" braces will be worn at the same time, limiting the space in between the knees even more.

To keep the forces on the soft tissue as low as possible, the orthosis utilizes the longest possible leverage. In general the length of the cuffs is between 230 and 270 mm. The cuffs are "O" shaped and are flexible to adapt for changes in the soft tissue while the leg is in motion.

A UNILATERAL-PHYSICAL-SAGITTAL KNEE BRACE



The orthosis must guide the bony structures of femur, tibia and fibula. These structures are mainly situated at the antero-lateral side of the leg; so the only very rigid component should be the extension of the upright at the antero-lateral side, all other parts are narrow and flexible, mainly for comfort reasons. All these properties were only possible with a hybrid-laminated frame, which is a compound of carbon, glass and matrix. The weight of each cuff could be limited to ±195 grams. Together with the joint, a completed orthosis will be less than 500 grams.

The orthosis consists of three parts: the tibial cuff, the joint and the femoral cuff, which are interchangeable. This means that a large thigh cuff can be combined with a medium tibial cuff, making it very easy to accommodate for variances in thigh and calf circumferences.

Data is being collected and will be reported when clinical trials are completed.

This product is protected by pending patents.

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Service Delivery & Public Policy
(Topic 6)

A EUROPEAN APPROACH TO ASSISTIVE TECHNOLOGY EDUCATION – TELEMATE

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ABSTRACT

Europe needs a more common ethos and approach to assistive technology and its provision. The European Commission has recognized that harmonized educational programs can contribute to this aim and will promote staff mobility. It has funded three related educational projects in assistive technology: EUSTAT, for end users (1), IMPACT, for intermediaries (2), and TELEMATE, for specialist. In the last year of its three-year program, TELEMATE (Telematic Multidisciplinary AT Education) has been testing its concept of a framework for education in the field. This framework provides a common philosophical approach, a pattern for the development of training packages and a database for teachers and students in all European countries.

BACKGROUND

Rapid development of Assistive Technology has made possible many new services and devices, but these have not always been accompanied by the necessary education and training of service providers. Lack of awareness, knowledge, skill, and understanding of the roles of their multidisciplinary colleagues can nullify the benefits that technological advances bring.

The HEART Line E study of teaching in assistive technology in Europe addressed some of these issues(3). TELEMATE is the practical outworking of some recommendations from the study. It has brought together educationalists and AT service providers from six countries to create a unified view of AT education that can be applied across the continent. In particular it aims to address two great difficulties: a) the broad areas of knowledge required of service provider teams for a holistic support of their clients, and b) that fact that users and members of their professional multidisciplinary support teams need different educational approaches, according to their background.

Its product will be a framework for multidisciplinary education and training that will allow integration of different local curricula, exchange of multimedia modules, and a means to maintain the expanding network of teaching resources.

METHOD

The HEART report E.3.2 identified three areas of education and training: Human, Socio-economic, and Technical, as shown in Table 1.

The field therefore requires both common-core and cross-disciplinary education. TELEMATE structures modules within the overlap areas of specialty (see Figure 1) to lead specialists from the edges of their own knowledge into the relevant areas of knowledge shared with the two other basic disciplines.

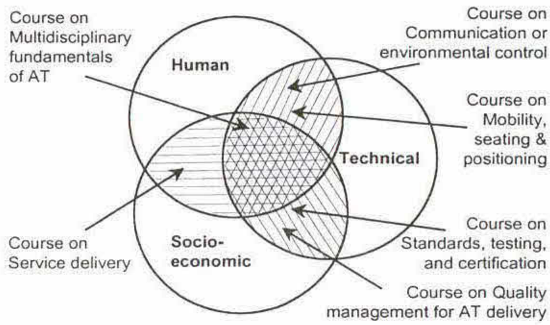

Figure 1 TELEMATE's Educational Model

Table 1 HEART report areas of education and training

HEART area	Basic profession	Underpinning disciplines
Human	Clinical	Anatomy, Physiology, Biomechanics, Disabilities, Psychology, Sociology, Knowledge transfer, and Ethics
Socio-economic	Administration	Management/service delivery, Standards/testing, Legislation/economics
Technical	Engineering	Mechanics, Electronics, Physics, Information technology, etc., and their practical embodiments in Assistive Technology devices classified under Communication, Mobility, Manipulation and Orientation

The Knowledge Framework

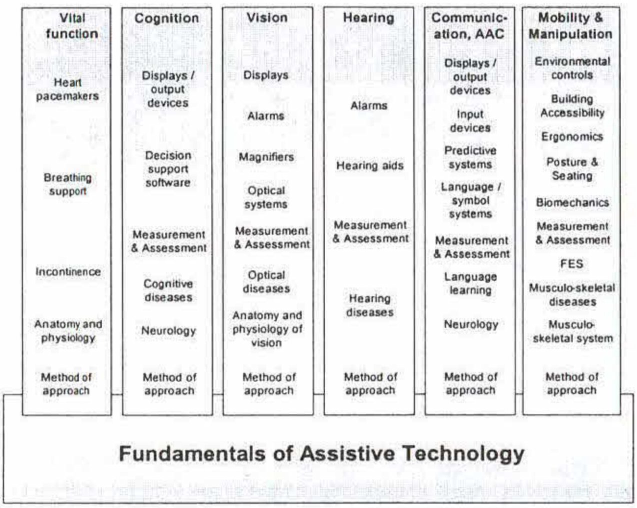

Figure 2 Fundamentals and Functional areas

The knowledge framework aims to create a common foundation to build the new science of Assistive Technology. This will enable all members of a team (including end-user and carer) to own for themselves the same shared concept of the potentials and limitations of AT. It has two linked parts:

i) the relationships between the foundations and application areas of AT and

ii) the relationships between other disciplines and the discipline of AT.

The groundwork is an understanding of disability as a phenomenon within personal, social, medical, environmental, and technical contexts. Figure 2 shows the groundwork and, beyond this, the various functional contexts. Following and extending the HEART Line E proposal, six areas are identified within which just a few examples are shown in the figure.

Database Framework

The database framework, which is currently under development, aims to link providers of AT courses to students. The vehicle will be internet-based so that potential course users and providers from all over Europe (and beyond) will have access.

The database classifies courses by Function and Context. Furthermore, the Subject area will provide a means of searching for information, see Figure 3. The TELEMATE team warmly welcomes comments about the suitability of the frameworks outlined here. For example, "Age" (development, middle

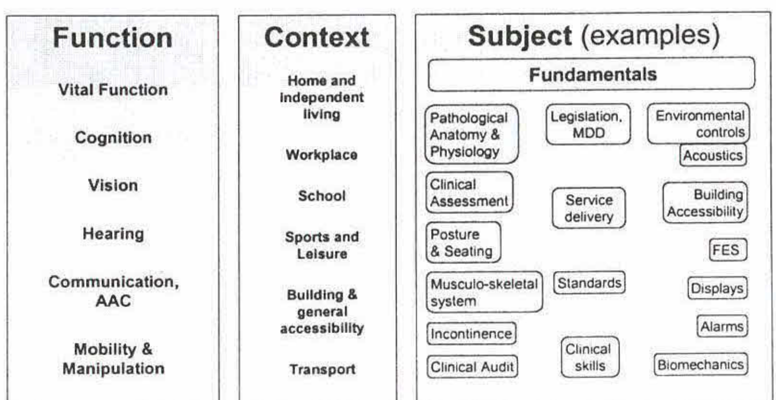

Figure 3 Classification areas for course database

age, old age) might be included in the Context classification of the database framework.

THE TEST COURSES

Conventional teaching material was classified with respect to the TELEMATE framework and common curriculum requirements of European services. This material was associated with appropriate teaching delivery methods, depending on the material and the context of delivery. Two model courses were then developed to test the frameworks: Fundamentals of Assistive Technology, and Computer Access. See Table 2. The courses have been designed to be suitable for specialist service providers from different professional backgrounds and with specific needs of knowledge. They use self-learning approaches where possible supplemented by learning situations supported by IT and/or classroom interaction. A flexible approach has been needed to handle the national and cultural differences in Europe. The courses were written in English. The issue of intellectual property rights of course modules (IPR) has been addressed by placing the onus on the course provider rather than the framework.

Table 2 Outlines of demonstration courses

Fundamentals in AT	Computer Access
1. Introduction to AT 2. Users and user characteristics 3. Modern rehabilitation principles 4. Individual plans for rehabilitation, including AT service provision 5. Characteristics of AT 6. Service delivery in AT 7. Design for all	1. Basics of Computer Technology for AT professionals 2. Benefit of Computer Access 3. Requirements on Computer Users/Which skills are necessary to use a computer? 4. General Trends / Mainstream 5. Basic Principles and Devices for Computer Access 6. Basic Preconditions for CA 7. Service Delivery Infrastructures 8. Case Studies

The presentation will include a report on the conduct and validation of these courses to be run in United Kingdom, Portugal, Germany, Sweden, Italy, and Norway.

Details of how to obtain the TELEMATE courses, access the course database and to obtain the public deliverables can be found at the TELEMATE web site, www.telemate.org.

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EDUCATING PROFESSIONALS TO TECHNOLOGY AND DISABILITY: THE ITALIAN EXPERIENCE

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Keywords: Assistive Technology, Educational Technology, Disability

Abstract. Two Postgraduate Courses have been designed and activated in Italy in order to provide a comprehensive educational offer for professionals who are involved in the application of technology for people with disabilities. The first Course is focused on Assistive Technology: it provides a wide-spectrum competence on principles and practice related to available technology for rehabilitation, independent living and social integration. The second course is focused on Educational Technology: it is addressed to the use of informatics in facilitating rehabilitation and school integration for people with cognitive disabilities and learning disorders. Both courses are run by SIVA in co-operation with the Milano Catholic University, who awards both Course Certificates.

1. Introduction

Assistive Technology (AT) Education is an hot issue today, due to both the increased awareness of the AT role in the rehabilitation and users empowerment process, and the need to ensure appropriate quality to the service delivery process [1]. Specific educational programmes are being developed in several Countries, embodied in educational curricula of professionals, or as accreditation/credentialing programmes (such as the RESNA-ATP certificate [2]), post-graduate courses, distant learning [3], in-service training and so on.

The Italian experience is young with respect to AT education; however it developed quite fast due to the need to ensure proper training to the professionals acting as AT advisers within the Italian network of local AT Information and Advice Centres [4]. Such Centres are chiefly run by the rehabilitation Centres of Local Health Authorities — and thus are mainly staffed with rehabilitation professionals — but also by User Organisations and Municipalities. Now the network includes some 110 Centres (until 1985 there was just one Centre — SIVA — and in 1990 they were still less than 20); the reason for such fast development is due to the SIVA CdRom information system, which played the twofold role of primary information resource and cultural catalyser of the process, the AT educational initiatives that SIVA gradually undertook starting with 1985, and the growing awareness of the information needs by both the end-users and the professionals.

In 1998 an agreement was signed between the Don Gnocchi Foundation and the Catholic University of Milano. Capitalising on the SIVA experiences, two educational curricula were designed and put into operation as Postgraduate Courses. They lead respectively to an Assistive Technology Certificate and an Educational Technology Certificate awarded by the Faculty of Educational Sciences. The Courses are described in the following.

2. THE POSTGRADUATE COURSE ON ASSISTIVE TECHNOLOGY

The full title of the Course is "Technologies for autonomy and social integration of persons with disabilities" (Tecnologie per l'Autonomia e l'Integrazione Sociale delle persone disabili). It is a 200-hours Course including 160 hours devoted to lessons and laboratory sessions, plus a 40-hours credit for the preparation of an individual thesis to be discussed at the end of the course. The Course is mainly addressed to rehabilitation professionals and other people who are involved in disability issues (educators, technologists etc..). However no restriction is established for any other persons willing to participate, provided they have a previous valid University diploma or degree. The maximum number of students is 40.

The course aims at providing a wide-spectrum knowledge on the available technologies for rehabilitation, autonomy, independent living, school integration and work for persons with any disability and age. Technological aspects, although representing the core of the educational curriculum, are looked at along with all related human and socio-economic implications, such as:

- the impact of AT usage on the individual, the primary network and the community
- the integration of AT within individualised rehabilitation or educational programmes
- the user's empowerment perspective.

Several sessions address the methodology of counselling, advice, choice and personalisation of AT in view of having it effective in meeting needs (competent), consistent with the user's lifestyle (consonant) and appropriate to the environment where it will be used (contextual) [5]. Training is also provided on making use of available information resources so as to prepare students for keeping themselves continuously up-to-date on the advances in the field.

The Course Programme is shown in the following table. Italics is used for laboratory sessions (teamwork on case studies, or hands-on sessions on assistive devices).

Course Assistive Technology	
Programme 1999	
Module 1 *(40 hours lessons and laboratory)*	Introductory Concepts Primary spaces of daily life (I) Primary spaces of daily life (II) Social spaces Body and Personal spaces
Module 2 *(40 hours lessons and laboratory)*	Mobility and Seating (I) Mobility and Seating (II) Mobility and Seating (III) Assistive Devices Assessment (I) Assistive Devices Assessment (II)
Module 3 *(40 hours lessons and laboratory)*	Computer access Augmentative Communication AT for visual impairments AT for hearing impairments Educational technologies for disability
Module 4 *(40 hours lessons and laboratory)*	Relating with the clients Empowerment of AT end-users Implementing AT with end-users AT counselling (I) AT counselling (II)
Module 5 *(40 hours lessons and laboratory)*	Compilation of thesis Thesis discussion

3. THE POSTGRADUATE COURSE ON EDUCATIONAL TECHNOLOGIES FOR DISABILITY

The full title of the Course is "Educational Technologies for Disability: selecting, using and programming informatic tools in the education and rehabilitation process for persons with cognitive and learning disabilities" (Tecnologie Didattiche per la Disabilit˙: scelta, utilizzo ed elaborazione di tecnologie informatiche nell'educazione e nella riabilitazione delle disabilit˙ cognitive e dei disturbi dell'apprendimento). It is a 220-hours Course including 120 hours devoted to theoretical lessons, 60 hours hands-on laboratory, and a 40-hours credit for a practical stage in educational or rehabilitation facilities. Students should also compile a stage report and an individual thesis to be discussed at the end of the course. The Course is mainly addressed to education and rehabilitation professionals, provided they have a previous valid University diploma or degree. The max. number of students is 30.

The Course aims at providing teachers, educators and rehabilitation professionals with adequate know-how related to the use of information technology within the education and rehabilitation process [6]. Besides delivering notions and practice on the most meaningful software applications in this field, the Course also deals with:

- diagnostic and phenomenological fundamentals of cognitive and learning disabilities
- epistemological issues, and
- the theoretical and methodological background related to educational technologies.

Specific attention is devoted to the design, the construction, the implementation and the evaluation of educational and rehabilitation processes that make use of technology applications [7]. The Course programme is shown in the following table.

Course Educational Technologies for Disabilities	
Programme 1999	
Theoretical sessions (120 hours)	
Epistemology and research	Epistemology and methodology of research in educational sciences Historical and epistemological profile of the theories of learning
Assistive Technology and disabilities	Computer accessibility for motor and sensory disabilities
Clinical issues	Learning disabilities: psychological and neuro-psychological aspects Cognitive impairment and learning Neuro-psychological assessment protocols in dyslexia
Educational sciences	Basics of pedagogy and special pedagogy Methodologies and tools for special education

Educational technologies	Introduction to educational technologies Technology in learning processes Bridging learning theories to the usage of educational technologies Cognitive processes related to the use of computer technologies Software tools as a support to education and rehabilitation: problems related to the selection and the use Developing and using information and communication technologies for children with disabilities Implementing new technologies in the formulation of educational or rehabilitation programmes Outline of possible telematics applications supporting educational activities
Laboratory sessions (60 hours)	
Practical stage in educational or rehabilitation facilities (40 hours credit)	
Individual Thesis	

4. CONCLUSIONS

Both courses are proving quite effective with respect to Italian context. The Educational Technology Course was held for the first time in 1998, with 17 participants having got the Certificate at the time of this publication.

The Assistive Technology Course started as University Course in early 1999, so the first Certificates will be awarded at the end of the year. However, a non-University Course had been held at SIVA for several years with a similar structure, although with a programme restricted to 120 hours. Such previous experience (which got an overall attendance of some 400 professionals from all over Italy) ensures that the way most notions are provided have already been extensively field-tested.

In both Courses major attention is devoted to prepare students to cope with the fast pace of technology development, so as to be able to choose and implement appropriate Assistive and Educational Technology event when products available today disappear from the market in favour of more up-to-date products. This involves providing the ability to make use of information resources, to evaluate products and to adopt a proactive attitude towards technology for the benefit of people with disabilities.

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A NEW GRADUATE COURSE IN ASSISTIVE TECHNOLOGY OUTCOMES MEASUREMENT

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ABSTRACT

This paper describes a new graduate course in assistive technology (AT) outcomes measurement. The course targets a multi-disciplinary student audience and is one of six courses that are offered as part of a transdisciplinary graduate concentration in assistive technology. Course content areas, instructional methods, and initial results are discussed. Suggestions for future refinement and adoption of this model by other AT training programs are given.

BACKGROUND

In the early-to-mid part of the 1990's there were a number of articles written that advocated for the necessity of outcomes research in the assistive technology (AT) and rehabilitation engineering (RE) fields [1-4]. Although the response to these early papers was not immediately apparent in the AT and RE literature, there is an emerging body of work, ranging in content from development of new measurement tools to quality assurance programs within service delivery contexts. In addition, an AT outcomes web site has been established as a repository for related information [5], and there is an active 'listserv' discussion group on AT outcomes [6].

In the United States there are approximately 20 graduate curricula that focus on rehabilitation engineering and/or assistive technology, and RESNA maintains a web site that summarizes these programs [7]. As summarized by Lenker [8], there have been numerous articles and conference papers written about individual programs. None have specifically mentioned inclusion of an outcomes measurement course as part of their curriculum.

OBJECTIVES

We felt that development of a graduate course in AT outcomes was essential if we were to foster a mindset among new graduates that outcomes measurement is part of their professional responsibility to the field. Our objective was to develop the course content and present the material as a graduate course for 6-10 students. As with other AT-related courses offered by our department, the target audience for this course included four groups: (1) graduate students enrolled in a transdisciplinary graduate certificate program in AT; (2) graduate students enrolled in the Master of Science degree program in Occupational Therapy, which includes assistive technology as one of three concentration areas; (3) graduate students who have an interest in AT and are matriculating in other departments; and (4) non-matriculating, community-based practitioners.

METHODS

Instructors: The diversity of content areas suggested the need for more than one instructor. The two authors of this paper have complementary backgrounds, and they worked together throughout all phases of curriculum development and course instruction. Approximately half of the class sessions were conducted by the second author, who has over 25 years of experience in the field of program evaluation. The first author, who has 10 years of experience in AT service delivery and graduate instruction, facilitated discussions related to application and critique of specific outcomes tools.

Content Areas: Topic areas included program evaluation, functional outcomes in rehabilitation, AT outcomes, and measurement tools in AT and related areas. Readings were identified from the primary literature in each area. The theories and practices of program evaluation emerged in the 1960's in response to the need for evaluation of educational programs, and the field has evolved steadily over the past 30 years. Among its principles of interest to AT outcomes research are: identifying relevant stakeholders and their priorities; raising specific evaluation questions relevant to service quality, intervention effectiveness and/or program impact; and designing procedures based on the corresponding indicators [9].

The burgeoning field of outcomes research in assistive technology offered the other focus of course readings. Measurement tools covered were the Psychosocial Impact of Assistive Technology Devices (PIADS) [10], Lincoln Outcome Measures for Environmental Controls (LOMEC) [11], the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) [12], Canadian Occupational Performance Measure (COPM) [13], Matching Person and Technology (MPT) [14], Quality Indicators in Assistive Technology (QIAT) [15], Environmental Functional Independence Measure (EnviroFIM) [16], and health-related quality of life [17].

Class Format: The class met for three hours each week throughout the semester. The instructors led discussions of the readings that encouraged active student participation. Supplemental hand-outs and exercises were created to complement and enhance the material on program evaluation.

Assignments: In addition to the primary readings, students were required to complete three projects: (1) a literature review related to outcomes measurement in a practice area of their choosing; (2) a proposal for program evaluation in a setting of their choosing. Students were encouraged, though not required, to complete their literature reviews on their anticipated area of program evaluation; (3) a conference-style poster that summarized their program proposal and was presented in a session that was attended by departmental faculty and graduate students.

RESULTS & DISCUSSION

Six students completed the course during Fall 1999 semester. Three were enrolled in a graduate certificate program in AT, one was a student in M.S. degree program in Occupational Therapy, one was a doctoral student in the Communication, and one was a non-matriculating physical therapy clinician from the community.

Although students struggled initially with the program evaluation concepts, they were very receptive to the overall course content. Since the final project required development of a program evaluation proposal, all students became familiar with the fundamental concepts and were able to apply them to their respective areas of AT interest.

Students were surprised at the paucity of published outcomes studies. They were both encouraged and daunted by the absence of previous outcomes studies in their particular areas of concentration. Both instructors offered encouragement that evaluation of effectiveness and impact were well within the capabilities of the students and were needed by the field as a whole. The students expended significant effort on completion of their final projects and posters, but all felt that these were worthwhile exercises.

Each instructor felt that the course would not have been possible without the contributions of the other. The first author's background in service delivery was helpful for facilitating discussions related to AT service contexts and use of the various measurement tools. The second author's experience with program evaluation was invaluable for guiding students through development and completion of their projects. Each instructor learned from the expertise of the other, and both contributed fresh insights during sessions in which they were not the primary discussion leader.

CONCLUSIONS

It is vital that graduate AT/RE programs offer courses in outcomes measurement in order to equip the next generation of service providers and researchers with the requisite skills and mindset needed to meet future challenges facing the field.

The fact that the program evaluation framework was applicable to the relatively broad number of settings represented in the students' projects leads us to suggest that this framework be explored further by those engaging in evaluation of AT service delivery programs. The authors intend to develop a paper that summarizes this content so that interested others from the AT and RE fields can apply it to their respective domains of research and practice.

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ASSISTIVE TECHNOLOGY EDUCATION FOR END-USERS: GUIDELINES FOR TRAINERS

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Keywords: Assistive Technology, Education, Empowerment

Abstract. Based on the findings of the EUSTAT study — an international project within the Telematics Application Programme of the European Commission / Dg13 — his paper offers a synthesis of the Guidelines developed for those who organise educational activities on Assistive Technology addressed at the end-users. The educational process is looked at within an empowerment perspective rather that as a mere transmission of notions. The effectiveness of education should be evaluated in relation to the increased ability of end users to make use of AT knowledge for improving their quality of life, and becoming informed, demanding and responsible consumers of AT products and services. To such end a number of critical factors are identified and ways to address them are discussed.

1. Introduction.

Education is a powerful means for facilitating empowerment of persons with disabilities to make informed and responsible choices of Assistive Technology (AT). This issue has been discussed in [1] in general terms, and in [2] with specific focus on education of end-users. Many educational initiatives on AT for end-users are being carried out in Europe and in several other Countries [3], often as part of broader programmes of rehabilitation, or independent living and self-determination training. The methods to carry out such education are virtually infinite: they depend on the amount and the extent of the knowledge to be transferred to the end-users, on the characteristics of the population trained, on the environmental context and so on. The transmission of knowledge is a process that deals with a somehow moving target; it never ends because *persons change in response to knowledge*: new horizons opens, new needs arise, new challenges appear. So it cannot be solved through the provision of a simple set of information and notions. It requires an *educational approach* assisting the persons in their changes.

The ***EUSTAT study*** — carried out by an international inter-disciplinary consortium within the Telematics Application Programme of the European Commission — worked at finding out ways and methods by which knowledge on AT can be directly transferred into the hands of *end-users*. To this end it developed *Educational material* for self-education of end-users [4], and *Guidelines and Tools* for those who organise or carry out educational initiatives. All the EUSTAT documents are available on the web [5]. This paper is based on the EUSTAT Guidelines [6]: it provides a quick synthesis of the points that should be considered and addressed by educators when designing courses or other similar initiatives.

2. FIRST STEPS: BASIC CONCEPTS

Before starting the design of any educational initiative, the organiser should have clear ideas around some basic concepts related to disability and AT.

The first keyword is of course ***Assistive Technology***, that needs to be understood in all its implications. ***Service Delivery*** systems should be also known quite well, as they influence the relation between the market offer and the end-users needs. The relation between AT and ***disability*** should be looked at within the general framework proposed by the World Health Organisation, the so called ICIDH Classification [7].

Concerning the AT outcomes, three terms seems well suited to describe the overall impact of AT on individual end-users: ***Quality of Life***, ***Autonomy*** and ***Empowerment*** [6]. These need to be properly defined, so as to avoid possible misunderstandings related to the different shades of meaning the may have in different cultural contexts.

There are other issues which the organiser should be aware of, if their educational initiative pursues empowerment. First, the move from a medical approach to a social approach, where end-users tend to regard themselves no longer as ***patients*** but rather as ***consumers***. Failure to acknowledge this view puts outside of the empowerment perspective. Secondly, it is possible to say that AT contributes to autonomy, and its knowledge contributes to empowerment; however this is true under certain conditions. The organiser should reflect upon ***how does AT contribute to autonomy*** and ***how does AT knowledge contribute to empowerment***. Third, the amount, the extent and the ***level of knowledge to be transferred to end-users*** is an important issue that has no unique answer, however some thoughts about the different kinds of knowledge that can be offered (*theoretical, practical, procedural* and *know-how*) may help to properly adjust educational programmes to the trainees' needs.

Finally, there is often a need to include some topics that are external to AT in themselves, but have a close relation with AT. Two such topics are recommended for inclusion in educational initiatives: the ***management of effective relationships with personal assistants*** and the ***peer counselling*** or ***peer mentoring*** role.

3. SECOND STEP: SETTING OBJECTIVES AND METHODS

The second step consists of deciding the mission, the format and the characteristics of the educational initiative. Some concepts borrowed from educational sciences may be helpful at this stage.

Five kinds of ***knowledge transfer processes*** can be identified. These are *counselling*, *training*, *teaching*, *information* and *awareness campaigns* [8]. Each of them has a different role and can be positioned differently depending on their stress on ***technical competence Vs initiative*** or on their ***target breadth Vs relationship with the user***. In the very meaning of the term, ***educational processes*** are those whose primary objective is learning. As such, they include only *teaching* and *training*. Learning is the result of a number of factors, one of them being the ***motivation issue***, that includes in turn the *motivation to learn* and the *motivation to change*. This involves ***focusing on active attitudes*** so as to prepare trainees for decision making and problem solving.

Four types of educational initiatives can be identified: courses, seminars, workshops and set of conferences. The decision on which is appropriate to each case, and how should they be organised, depends on several *critical factors* [8] such as: positioning factors; factors related to the transfer of knowledge to the group; factors related to the reception of knowledge by the individual; factors related to the transfer of knowledge into initiative.

4. THIRD STEP: ORGANISING THE EDUCATIONAL INITIATIVE

During the organisational phase, the contents should first be decided. AT may be the sole topic dealt with, or be just one out of several topics addressed by an educational initiative having a broader scope. The EUSTAT Guidelines concentrate exclusively on AT knowledge, which according to the ***HEART model*** [9] can be looked at as composed of ***technical components***, ***human components*** and ***socio-economic components***. For each component a number of topics is identified that Course organisers may decide to pick up in order to build educational programmes. Whereas most topics fall clearly within a component, there are some topics (e.g. seating systems or recreational aids) whose placement is somehow arbitrary.

Then the educational initiative has to take shape and be put into operation. The design has to go through a ***planning stage***, in which decisions are taken concerning the trainees group and the teaching team, a ***launching stage***, where the initiative is advertised and the trainees recruited, an ***organisation stage*** dealing with practicalities and an ***evaluation stage***, through which the success and the outcome of the initiative can be verified.

The knowledge delivery process has to take into account pedagogical issues such as ***didactic methods*** and teaching ***tools and strategies***.

In the design process all critical factors should be taken into account. However, at this stage the factors related to the transfer of knowledge to the group of trainees have a major influence: these are *contents* factors, *pedagogical* factors, *targeting* factors, and *management/organisational* factors. They establish the overall characteristics of the educational initiative, and the framework within which each educator will act.

5. FOURTH STEP: ADJUSTING TO THE AUDIENCE

After the educational programme is designed, the educators role is to fulfil the mission while ensuring that each trainee achieves the planned learning objectives at their best. Factors that may influence the individual reception of knowledge by the individual are ***predisposition factors***, ***disability-related factors***, ***individual attitudes towards disability***, and ***individual expectations***.

However, an AT course that runs in complete isolation from the world would make no sense. The main indicator of the Course success is the trainers' ability to make use — after the Course and in real life — of the knowledge received. Harnessing the notions to the end-users' living context is a major challenge for educators. This basically means to take into account factors related to the ***living environment***, to the existence of community services offering ***social support***, to the ***AT market*** and to the ***social network*** around the individual.

6. CONCLUSIONS

The outcome of an educational initiative should be measured primarily in terms of the empowerment it has fostered in each person who took part. The critical factors discussed above were identified in view of this very objective. If all these factors are addressed satisfactorily, there are good reasons to believe that the educational initiative will be successful.

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A SURVEY OF ASSISTIVE TECHNOLOGY PROVIDERS SOME INITIAL RESULTS

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ABSTRACT
This paper presents data from a survey of assistive technology service providers. The survey utilized the World Wide Web to collect data. A brief review of an earlier survey is presented then the methodology used in this survey. The questions used in the survey instrument are provided. Some initial results are presented with a discussion of problems involved in analyzing textual data gathered through comments questions.

INTRODUCTION
In 1991, Larry Trachman published survey results on Rehabilitation Engineers (RE). (Trachman) These showed that RE's worked in six major areas with 50% in service delivery and 33% in research and development. The primary work locations were 15% hospitals, 14% private practice and 11% universities. Annual salaries ranged from $33,000 to $56,500 with an average for bachelors of $37,900 and Masters of $39,300. Tasks undertaken covered the range of assistive technologies with computer access, worksite and home modification, environmental controls, mobility and seating and positioning being prominent. The concentration of RE's were population driven with the fewest numbers in the Southwest and Western areas. The total number of RE's reported by region was 119. Since 1991 there have been papers published on various training programs and manpower needs in the area but no similar survey of providers in the field. (Rowley)

This past year a survey instrument was designed to gather information not only from RE's but all providers of assistive technology. It had two parts. The first, which is being reported on in this paper, consisted of 45 questions. The second part gathered information on technical skills and will be reported on later.

METHODOLOGY
This survey was designed for use on the World Wide Web. It was available through our Rehabilitation Engineering web site but required going to a specific file that was not part of the home page. This was done to limit input to providers and not just anyone who visited the site. The survey was announced through the RESNA list server several times during August of 1999.

The first part of the survey consisted of 45 questions. It gathered basic demographic data through 19 questions and then answers to 26 specific questions, see Table 1. Demographic data involved name, address, phone, fax, e-mail, employer, employer location and employer contacts such as supervisor and phone number. Some of the questions covered areas that Trachman reported on. Other questions involved certifications, hours of work, benefits, travel, and continuing education. Several provided the opportunity to write comments. Comments were limited to 225 characters or approximately 40 words.

Table 1 – Survey Questions

Demographic questions:	First Name, MI, Last Name, Street, City, State, Zip Phone, Fax, E-mail, Employer, Supervisor's Name, Street, City, State, Zip, Phone, Fax, E-mail
Specific questions:	1. What is the highest level of education that you have completed? 2. What is your highest degree in? 3. What certifications do you currently have? 4. What certifications are you pursuing? 5. What areas of specialty have you developed within the rehabilitation field? 6. What categories of disabilities do you work with? 7. Which entities do you work with? 8. Do you enjoy your work? 9. Are there any specific difficulties related to your position that you are experiencing? 10. Select the type of business in which you are employed? 11. How many employees are in your workplace? 12. Do you work with other rehabilitation engineers on a regular basis? 13. What other types of rehabilitation professionals do you work with (OT,PT, pathologists...) 14. How many hours do you work per week? 15. Is regular travel required with your job? 16. What is your current salary? 17. Approximately, what is your benefit package worth? 18. Do you have continuing education needs? 19. Have you continued your schooling? 20. Do you have the RESNA Assistive Technology Provider certification? 21. Are you pursuing additional certifications? 22. Which conferences do you attend? 23. Which conferences do you value most as an Assistive Technology Provider? 24. Do you think there is a need for more Assistive Technology Providers in your geographical area? 25. Which professional societies are you a member of? 26. Additional Comments?

RESULTS

Data from five questions involving input from 61 providers during a two week period in August 1999 are provided, Table 2. Further survey input was not requested as the methodology for handling analysis of comment sections proved cumbersome as the number of inputs increased.

Table 2 – Some Initial Results

Years Worked	Salary Range	Benefits %	Education	Degree
30	61K+	10	BS	PT
29	20K-30K	0	Asso	OT
25/2	51K-61K+	21-31+	BS/MS	OT/?
20/2	41K-61K+	21-30	MS2	Spec Ed/Engr
19	61K+	0	MS	BA
17/2	51K-61K+	10-20	BS/PhD	PT/Computers
16	41K-50K	21-30	High Sch	------------
15/2	31K-50K	21-30	Hi Sch/MS	CS/3yrs college
14/3	41K-61K+	10-31+	BS/MS2	OT/Engr/Decision Sci
11	41K-50K	31+	MS	Education
10/6	20K-50K	10-31+	BS/MS5	OT/Engr/Ed/Speech
9	61K+	0	MS	Human Factors
8/5	31K-61K+	0–30	HS/MS3/PhD	Engr.
7/4	20K-60K	0-30	BS2/MS/PhD	OT/Engr
6/3	31K-50K	10-30	BS/MS2	Engr/Tech/Systems
5/5	30K-61K+	0-30	Asso/BS2/MS2	OT/Engr/Human Ser
4	61K+	21-30	PhD	Education Psychology
3/4	20K-40K	0-20	BS/MS3	OT/SpecEd/Engr
2/5	31K-50K	10-30	BS/MS5	OT/Engr/Pub Health
1/4	20K-50K	10-20	BS/MS3	OT/Rehab/Speech

DISCUSSION

Obtaining survey input via the RESNA list server required posting a call every two or three days. Each posting resulted in several responses. Input was received from a cross section of providers with education levels from High School to the Ph.D. Their expertise came from expected areas such as OT, PT, Speech and Engineering and unexpected areas such as Decision Science and Education. Years worked versus salary does not correlate well. Educational level versus salary does much better with higher salary relating to advanced degrees. There are exceptions. Benefits ranged from 0% to more that 31%. It would be interesting to look at other data and see if 0% benefits relates to self employed.

The analysis of comment sections is being studied using a data mining approach. This offers hope for quickly pulling out the important information without having to resort to reading them then offering a synopses.

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PROVISION OF ELECTRONIC ASSISTIVE TECHNOLOGY IN TWO REGIONAL HEALTH AUTHORITIES

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ABSTRACT

This paper reports the results of a study investigating the provision of EAT within a given geographical area [1,2]. Provision is viewed from both the agencies and the user's viewpoint. Questionnaires were sent to funding agencies requesting information on the equipment provided. Users were questioned on the range of equipment they use and any problems they had obtaining it.

Results showed that provision across the area of interest was inconsistent. Differences in the range of equipment and level of provision were dramatic. Users reported a range of problems relating to funding issues, information availability, delays and access. The paper highlights the effects this inconsistency can have on the user and emphasises the importance of interagency co-operation.

INTRODUCTION

In England electronic assistive technology (EAT) can be obtained via a number of sources. These include several statutory agencies (Health, Social Services and Education), charities as well as through private purchase. For people with complex physical disabilities who need more than one device this can mean several referrals are required followed by an equal number of assessments and possible waits for the equipment to arrive.

An additional complicating factor to this fragmented approach is that social and education services in England are controlled at local government level. Therefore decisions on budget allocation, eligibility criteria and range of equipment to offer can be determined locally. Anecdotal evidence indicated that because of this, the level of provision was not uniform within the geographical area covered by North Thames (West) and South Thames (East) regional health authorities; the level of inequity was unknown. General information [3] giving overviews of the system is available but it does not provide a complete picture as only general indicators of what *may* be available and where to obtain further information.

A study was undertaken to identify the differences in provision that exist across a given geographical area and to examine peoples experiences of accessing agencies for the equipment they needed.

METHOD

The area covered in the survey was that contained within what was North Thames (West) and South Thames (East) Regional Health Authorities. To indicate the population within this area there is estimated to be in the order of 90,000 wheelchair users.

Questionnaires were sent out to statutory agency offices in the geographical area under investigation. These included social services (62 offices representing local authorities), education authorities (25), charities (33). Data requested included:

- Equipment provided
- Level of funding available
- Common joint funding partners
- Referral methods
- Limits on funding
- Eligibility criteria

As the project was aimed particularly at investigating the provision of EAT from different agencies, the user survey targeted those most likely to use more than one piece of EAT, i.e. those with multiple physical disabilities.

RESULTS

The range of equipment provided by the agencies in the study and the overlap is indicated in figure 1.

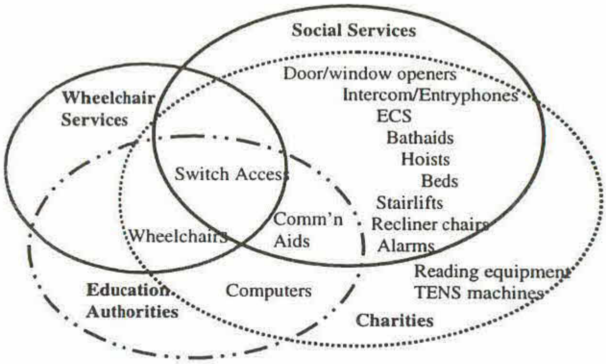

Figure 1. Range of equipment quoted by agencies and the overlap

Social Services

The response rate to the questionnaire was 82%. The results are summarised below.

- The range of equipment provided varied widely. From a standard list 9% services offered only two items and 27% offered seven. Funding levels also varied greatly.
- All respondents reported the use of eligibility criteria, often drawing from a common document but often including additional criteria.
- Joint funding was used with partners quoted as being charities, users and health authorities.
- Three (27%) of respondents reported a limit on funding for a single item (£1000-£2000). A further three reported a limit above which higher approval was required (£500 - £2000).

Charities

The response rate to this questionnaire was 63%. The results are summarised below

- Sixteen (80%) of the charities that responded only partially fund equipment.
- The funding level is between £200 - £500.
- The numbers applying for this funding reported as increasing annually
- A wide range of equipment was reported as being funded

Education Authorities

The response rate from this group was 60%. The results are summarised below:

- Most commonly funded items were computers, communication aids, powered wheelchairs and switch access
- Budget management varied; twelve respondents (80%) manage the budget centrally two (13%) have devolved the budget down to schools, the remaining reported a mixture.
- Referrals for equipment were accepted from a variety of people and at different times.
- The majority of respondents (60%) did not use joint funding and had no mechanism in place to facilitate such an undertaking.

Wheelchair Services

The response rate from this group was 45%. A summary of the replies is given below.

- Wheelchair services keep only very basic data on users. Some were unable to give the number of powered and manual wheelchair users.
- In general, wheelchair services kept no data on other equipment users may have.
- Five services (50%) reported that they do not provide special/adapted controls to users.

Users

The response rate from this group was 53%. A summary of the results is given below:

- Each respondent used on average three items of EAT. (35% > 3 and 1% > 6).
- More than 90% of the devices cited were reported as being used regularly.
- Sixty per cent of respondents reported problems with the provision process.
- Problems existed in one or more of the following areas: funding, information availability, delay, maintenance and training and switches/access.

DISCUSSION

Figure one shows that a wide range of equipment is provided by the agencies contacted. However, the data indicates that this may provide a false picture as there is a wide variation in the provision of EAT within the geographical area considered. This means that users living within one mile of each other could have very different experiences in obtaining the same pieces of equipment. There are also areas of overlap between these agencies and therefore the user requirement dictates which agency would be approached to provide funding for a piece of EAT. Because of the overlap, confusion occurs when a need does not fall neatly into one remit as each agency may dispute responsibility for the provision of the item.

In general the provision of an item of equipment is viewed in isolation and rarely are the user's needs seen as a whole. An example of this lack of co-ordination was the inability of wheelchair services to provide information about an adapted controls service if required. It may also indicate gaps in the knowledge of those working in rehabilitation services.

The responses to the users questionnaire show how the differences in provision, and the fact that so many agencies acting, in the majority of cases independently, affect the user. Lamb's survey [4] reported that many disabled people wanted more independence. Many felt they could achieve this if they were better equipped. Varying eligibility criteria and level of provision therefore adversely affects a person's ability to gain that independence.

Agencies in some areas have reported the establishment of joint funding committees to overcome some of the problems associated with the variations in provision. Closer co-operation between services and sharing of information can help to overcome many of the problems reported by users and close some of the gaps that currently exist in provision of EAT.

In acknowledging the problems that users experience and seeing the inequities that exist in the current provision of this equipment it is hoped that professionals will look to their own practices. They should make themselves more aware of the other agencies at work in this field; and endeavour to share information more effectively between themselves and with users.

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COORDINATING WHEELCHAIR PROVISION IN DEVELOPING COUNTRIES

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ABSTRACT

An estimated 20 million people worldwide need wheelchairs but do not have access to them. One common strategy of wheelchair provision is to distribute refurbished secondhand chairs which have been collected from the United States and other wealthy nations. Another strategy is to work with people who live in developing countries to locally manufacture wheelchairs. A survey of organizations which use one strategy or the other found a general consensus that both approaches could be valuable provided that certain guidelines were followed. Organizations felt that through increased communication they could better coordinate their efforts, and that through improved outcomes measurement of various strategies a more effective system of international wheelchair provision could be established.

BACKGROUND

Approximately 20 million people worldwide who need wheelchairs do not have them. One strategy of meeting this need centers around collecting secondhand wheelchairs from developed nations, refurbishing the chairs, and distributing them to people with disabilities in developing nations. Hope Haven International Ministries and Wheels for the World are two organizations which use this method. Another strategy, employed by Whirlwind Wheelchair International and Motivation among others, involves working with residents of developing countries to establish facilities which manufacture wheelchairs locally.

OBJECTIVE

The objective was to collect information and ideas which could be used to better coordinate efforts to meet the mobility equipment needs of people in developing countries. This included gathering various perspectives about the strengths and weaknesses of importing chairs vs. locally producing them, and collecting ideas about how organizations might better integrate these strategies.

METHOD

Telephone interviews were conducted and written questionnaires distributed among individuals who work to provide wheelchairs to developing countries. Those surveyed represented organizations which use the strategy of distributing imported chairs as well as organizations involved in setting up local manufacturing facilities. Respondents were asked to give their opinions regarding the unique features of the two strategies, how the current efforts of various groups can be better coordinated, and how in the long term the best system can be devised to serve all needs.

RESULTS

General Principles of Responsible Wheelchair Provision

The overwhelming response of organizations polled was to emphasize that several services must always accompany each wheelchair distributed. The provider must work with the recipient to assess individual needs and ensure that the design of the chair is appropriate to the particular user. The provider must ensure that the chair fits correctly and that the seat cushion is adequate for the rider.

The rider must receive training in pressure ulcer management and the use and care of a wheelchair. Provisions must be made to ensure that the chair can be repaired, and follow up assessment should be done to determine whether the equipment meets the person's needs. The general message was that whether the chair itself is locally produced or imported, the results of neglecting these additional responsibilities can cause injury to the recipient of the chair. A wheelchair with an inadequate cushion can be fatal to a rider who has not been educated in pressure ulcer management.

Unique features of imported and locally produced chairs

An advantage of distributing imported chairs is the capacity to immediately meet the need for wheelchairs in areas where the demand for wheelchairs far exceeds the local manufacturing capability. Some importers have addressed the local unavailability of import repair parts by organizing distribution to limit the variety of different models of chairs in a particular area, making it more feasible to train local mechanics in the repair and adjustment of that chair and to supply repair parts.

The locally manufactured chairs can be designed specifically for the environment in which they will be used. The design of the chair can incorporate features to address various local conditions, such as travel over rough, unpaved roads, use of pit toilets, and the fact that many life activities such as meals take place at ground level rather than at table height. As the chairs are manufactured locally, any part of them can be repaired locally. Chairs can often be custom built to a particular rider's measurements. However, without thorough initial investment and skillful, committed local management, the shop may never become sustainable.

Concerns about free wheelchairs

Organizations which rely on sales of their product for part or all of their operating costs are harmed when the local market is flooded with free wheelchairs. Hospital administrators, government officials and even the people receiving the chair (who may have never ridden a chair before) often choose a free chair even if it is inappropriate to the rider's needs.

Need for Communication

The organizations surveyed felt that the first step towards effectively coordinating their efforts is improved communication, not only among international nonprofit agencies but also between those agencies and whatever wheelchair industry or organizations of people with disabilities may already exist in the region where operations are planned. Some organizations reported difficulty finding out where efforts at mobility provision were underway, and a desire was expressed to establish a frequently updated master list of the activities of all organizations involved in wheelchair provision efforts worldwide. In addition to coordinating logistics, organizations desired the opportunity to communicate the reasoning behind their strategies with other organizations.

Correspondence between organizations could be facilitated by tools such as group e-mail lists, as well as by creation and distribution of published materials. Groups cited the 1999 RESNA conference as a successful forum in which ideas regarding mobility provision in developing nations were exchanged. The Association of Mobility Providers conference, held this past year in Guatemala, provides another venue more accessible to organizations based in developing areas.

Coordination of Efforts and Integration of Strategies

In some instances, imports and locally produced chairs serve different consumer groups and thus can potentially serve the full spectrum of needs without interference. Hospitals often have a need for hospital models. A distinction was made between the technology needs of active adults who self-propel over harsh environments daily and persons who use their chair exclusively indoors and may not self-propel. A distinction was also made between rural areas, where the ability to repair the chair using local materials is extremely valuable, and larger urban centers where the stockpiling of imported parts and the centralization of special repair knowledge is more feasible.

There was interest expressed by the importers about integrating local labor into their distribution model. Currently, the Ministerios Cristiano Bethel, a Hope Haven International Ministries partner in Guatemala, refurbishes imported chairs on site using labor from the local community. Wheels for the World is in the process of establishing and supplying a similar shop in Accra, Ghana. Both organizations are exploring the possibility of modifying the imported chairs at these facilities to improve their suitability for local use, and wish to obtain the assistance of those familiar with locally appropriate technology. The simplest retrofit suggested is the local fabrication of low-cost seat cushions to accompany import chairs which lack cushions. The RESNA-sponsored SoreButts cushion design competition has collected numerous designs appropriate for this purpose.

Outcomes Measurement

In addition to coordinating current efforts, the organizations surveyed expressed an interest in objectively evaluating the effectiveness of each strategy used. A large body of anecdotal evidence exists about the successes and failures of particular wheelchair designs and distribution strategies in particular situations. Many felt that more rigorous and better documented methods of outcomes assessment were needed in order to better understand the role that each strategy should play in the future. Several organizations have offered to make whatever records they have available to anyone with the resources to conduct such a study.

DISCUSSION

The consensus was that given the 20 million wheelchairs needed worldwide, there is a place for all methods of wheelchair distribution, provided that the following services accompany each wheelchair distributed: Assessment of the client's needs in order to provide a proper fit in an appropriate chair, training in the chair's safe and effective use, follow-up evaluation, and establishment of a system for the long-term maintenance of the chair. There is an immediate need for better communication among groups which are working towards common goals of promoting health and independence. There is a long-term need to more accurately document the successes and failures of each strategy to discover the best place for each in an integrated mobility provision effort.

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Hope Haven International Ministries, Rock Valley, IA, http://www.hopehaven.org/internat.htm
Motivation, Bristol, UK, http://www.motivation.org.uk/
Whirlwind Wheelchair International, San Francisco, CA, http://whirlwind.sfsu.edu/
Wheels for the World (Joni and Friends), Agoura Hills, CA
http://www.joniandfriends.org/outreach/wftw/wftw.htm

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PENNSYLVANIA'S ASSISTIVE TECHNOLOGY LENDING LIBRARY
A Successful Inter-Agency Service Delivery Program

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ABSTRACT

Assistive technology lending programs have been in operation for many years as a strategy to improve identification of appropriate technology. Some of these programs sponsored by associations limit borrowers to their own members/consumers. In comparison with these programs, Pennsylvania's Assistive Technology Lending Library is a free, cross-age, cross-disability program, whose eligibility criteria simply are the need for assistive technology and residency in Pennsylvania. This paper describes the interagency approach to developing Pennsylvania's Assistive Technology Lending Library.

BACKGROUND

Assistive technology lending programs have been in operation for many years, and are a strategy to improve identification of appropriate technology, decrease abandonment of AT (1), and assist in capacity building (e.g. providing opportunities for pre-professionals as well as practitioners to learn about and try devices). Some programs sponsored by associations such as United Cerebral Palsy and Multiple Sclerosis, limit borrowers to their consumers. North Carolina's "Tech Act" project developed "Check it Out" to coordinate small lending programs throughout the state (2). In addition, some states financed programs to facilitate access to AT, although borrowers are limited by age or program eligibility. Pennsylvania was a leader in developing a technology lending program for children served by the PA Department of Education, established over ten years ago.

Since 1992, the Institute on Disabilities, Pennsylvania's University Affiliated Program at Temple University has received federal funding through the Technology Related Assistance for Individuals with Disabilities Act, its 1994 Amendments, and now the Assistive Technology Act of 1998. Needs assessment conducted in preparation for the initial application for federal funding revealed that Pennsylvanians with disabilities not eligible for AT loans through the education system had a difficult time obtaining devices for trial use. As a result, Pennsylvania's Initiative on Assistive Technology (PIAT) implemented the Short-Term Equipment Loan Program.

As a result of the success of the Short-Term Loan Program, encouragement from PIAT's Advisory Board, and the commitment of five state departments (Aging, Education, Health, Labor and Industry, and Public Welfare), efforts were begun to obtain state funds to expand the program. Grassroots support was garnered, and the program was promoted through the Disability Budget Coalition, a cross-disability group which annually proposes disability programs to the General Assembly. Ultimately, funding for the program became a component of the Governor Ridge's "Disability Agenda" (3), included in his budget proposal, and approved by the General Assembly in the Commonwealth budget for 1997-1998. Given PIAT's experience with the short-term program and a statewide infrastructure, the Institute on Disabilities was designated as the contractor to operate Pennsylvania's Assistive Technology Lending Library. Oversight is provided by representatives from the five departments listed above, through an "Intergovernmental Management Team".

The Center for Assistive and Rehabilitative Technology (CART), an AT service delivery program of the Pennsylvania Office of Vocational Rehabilitation, Department of Labor and Industry was developed in 1995 and located at the Hiram G. Andrews Center (HGA), a comprehensive, state-run rehabilitation facility. CART professionals provide integrated and personalized AT services from evaluation to recommendation to provision of assistive devices. To complement services and to accommodate individuals with disabilities at HGA, the CART AT Loan Program was implemented. This AT loan program provides individuals residing at HGA with accommodations in the classroom and dorm rooms for the length of their stay, ranging from a few days to several years.

Noting HGA's expertise in the provision of assistive technology services, The Institute on Disabilities approached HGA about collaborating in the operation of PA's AT Lending Library. HGA became the partner responsible for the circulation of AT devices. Strong communication and responsiveness between HGA and The Institute on Disabilities has been critical to the efficient and successful operation of the loan program.

PENNSYLVANIA'S ASSISTIVE TECHNOLOGY LENDING LIBRARY

As an inter-agency service delivery program, the purpose, philosophy and scope of PA's AT Lending Library are to:

1 Offer Pennsylvanians with disabilities the opportunity to try assistive technology devices in the setting they will be used, before they acquire them;

2 Allow AT service providers the option of showing their clients a larger variety of AT devices, and to allow for longer trial periods;

3 Provide educators (e.g. those involved in pre-service training in such disciplines as medicine, occupational therapy, speech-language pathology, education) with AT demonstration kits and equipment for professional and consumer presentations/training; and;

4 Disseminate information about AT devices and services (including funding).

PA's AT Lending Library is a free cross-age, cross-disability program, with the only eligibility criteria being the need for assistive technology and residency in Pennsylvania. Key to the program are the guiding principles of consumer choice, consumer direction, and good customer service. A prescription for the device is not required, nor must the assistive technology be specified as part of a rehabilitation/education plan. Inventory includes devices useful for individuals of all ages with physical, sensory, and/or intellectual disabilities in school, home, community and work environments. New equipment is purchased as it is recommended by consumers, by professionals in the field, or if it is a popular item for which many consumers are waiting.

During the first year of funding of PA's AT Lending Library, (1997- 1998), the Institute on Disabilities held a series of stakeholder meetings across the state to gather input from individuals with disabilities to determine how the program should operate and to collect suggestions regarding what technology to include. The initial inventory in excess of $400,000 was identified and ordered. In its second year of funding, circulation of AT equipment was initiated, with a grand opening in October 1998.

DISCUSSION

PA's AT Lending Library builds upon PIAT's infrastructure of Assistive Technology Resource Centers (ATRCs). There are 10 ATRCs serving the state: including entities such as UCP, Easter Seal, and centers for independent living. ATRCs serve as a resource for information and referral, provide initial processing of loan applications, and assist in facilitating equipment returns. In addition, more than 125 agencies and organizations across the state have volunteered to be "local branches", assisting in activities to promote the lending library.

Since the inception of the program, more than $500,000 has been spent on assistive technology devices. Nearly 2000 pieces of AT equipment are in the inventory ranging from low cost devices such as adaptive writing aids, to augmentative communication devices and laptops loaded with software that permits voice input, screen magnification, and screen reading costing thousands of dollars. There is no cost for the consumer, with funds for shipping and pickup included in the budget.

Consumers of PA's AT Lending Library are most often individuals with disabilities, but also include professionals who borrow equipment for demonstration, training, or to use during an AT evaluation. Over half of the loans (59%) processed were to individuals with disabilities, 34% were service providers, and 7% were to "other", usually family members of individuals with disabilities. Recipients of loans span the full spectrum of age, from 2-98 years.

To assess the quality of the program, a satisfaction survey is mailed to loan recipients within a month of the return of the device. In the first year of operation, 20% responded to the survey. Almost 80% of the returned questionnaires indicated that the equipment loan helped the person decide what device was most appropriate for their need.

Demand for the program grew from three AT devices shipped in July 1998, to 329 devices shipped in July 1999. Demand for the program continues to grow, with 442 devices shipped in November 1999.

PRELIMINARY CONCLUSIONS

Continuous interagency collaboration is a critical component for the successful implementation of PA's AT Lending Library.

PA's AT Lending Library satisfies a need reported by individuals with disabilities, providing them the opportunity to try assistive technology. This gives consumers confidence in their decision to acquire AT devices.

PA's AT Lending Library allows for better recommendation of AT devices. In a typical AT evaluation, all the equipment is tried in the period of a few hours, in a clinical setting with the decision taking place at the end of the evaluation. The AT Lending Library permits a longer trial at the location the device will be used. It also makes equipment available which evaluators may not have access to through their own programs, increasing options for consideration by the consumer.

PA's AT Lending Library serves as a teaching tool by providing demonstration kits and equipment for presentations and training, increasing public knowledge about and use of assistive technology. In addition, use of equipment as a part of professional training can improve the availability of a rehabilitation work force knowledgeable about assistive technology.

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TRANSITIONAL LIVING PROGRAM IN HOME-SIMULATED ENVIRONMENT A NEW SERVICE OF THE WEST VIRGINIA DIVISION OF REHABILITATION SERVICES

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ABSTRACT

In West Virginia, the Division of Rehabilitation Service is responsible for providing comprehensive rehabilitation services to people with disabilities. As a part of these services, a plan was initiated to develop a non-medical, consumer-directed Transitional Living Unit (TLU) program in a home-simulated environment. To implement this program, a team of representatives from independent living centers, assistive technology providers, administrators of the Division of Rehabilitation Services, and external consultants was established. This paper describes the four major components identified by this team to implement an innovative TLU program. It also presents the current status of these four components and the expected outcomes of the TLU program.

INTRODUCTION

In West Virginia, the Division of Rehabilitation Service offers comprehensive rehabilitation services to people with disabilities. As a part of these services, a plan was initiated to develop a non-medical, consumer-directed Transitional Living Unit (TLU) program in a home-simulated environment to assist individuals with severe disabilities towards independent living.(1)

The establishment of a TLU program has been based upon the need and benefit towards numerous individuals with disabilities requiring specific services to successfully re-orient and/or re-integrate into society and their local communities post-injury.(2) To achieve the proposed TLU program for clients of West Virginia, a coalition was formed that included West Virginia Division of Rehabilitation Services (WVDRS), West Virginia Assistive Technology System (WVATS), West Virginia Statewide Independent Living Council (SILC), and regional Centers for Independent Living (CIL).

The coalition identified four major components as key elements for implementation of the TLU program. These elements are building layout, assistive technologies, training curriculum, and administrative infrastructure. The purpose of this paper is to describe issues and the planning process of each of these components.

DESCRIPTION OF TLU PROGRAM COMPONENTS

<u>Building Layout</u>

The building layout consists of six individual units that simulate the type of residential environments in which West Virginians reside. These units include a two-bedroom townhouse, three different sized two-bedroom apartments, a two-bedroom mobile home, and a hotel room. The selection of these living environments correlates with population census data.(3) Each unit is equipped with:

1. two accessible entrances that are electronically operated
2. an accessible bathroom with either a roll in shower and a tub or a rolling shower alone.
3. height adjustable kitchen cabinets
4. electric curtain and window openers

5. chemical and fire alarm systems for physical and sensory impaired individuals
6. accessible deck and porch lift
7. cable, phone, and internet access

In addition to all of the above, the townhouse was designed as a smart house unit with voice activated controls.

Assistive Technology

In WVDRS, the Rehabilitation Technology Unit (RTU) delivers assistive technology services. Until now, the RTU has been providing field services in the areas of environmental modification (ramps, lifts, and home accessibility), computer access, augmentative communication, and driver evaluation (hand control evaluations and on-site training). With the opening of the TLU project, new assistive technology service areas will be added. These areas will consist of environmental control systems, home automation, and ergonomic work-site design and evaluation. To facilitate these new services, a large collection of new equipment has been purchased. The equipments include:

1. voice, computer, and switch activated environmental control systems
2. computers and height adjustable workstations
3. accessible phones
4. electrically operated beds
5. home automation components

The new equipment will be housed at the new assistive technology resource room. At this resource room, TLU clients will receive initial evaluation and training on these advanced systems.

Training Curriculum

The Training Curriculum is presently being developed by a committee that comprises of staff from the West Virginia Rehabilitation Center, West Virginia Statewide Independent Living Council (SILC), and the regional Centers for Independent Living. The committee plans to include courses regarding self-care, household management, financial management, personal care attendant management, transportation, mobility, recreational skills, and educational and vocational skills. Training will be customized to address individual needs. In addition, specific training will be conducted on appropriate use and care of assistive devices. Finally, the training curricula will extend beyond the individual to address training of selected family members, personal attendants and if possible some key community members.

Administrative Infrastructure

To guarantee an effective TLU operation, a functional administrative committee has been established. Members of this committee include authorities of the WVDRS, WVATS, SILC, CILs and external consultants. As part of their responsibilities, the committee has defined the mission, goals, client eligibility criteria, admission procedures, residential policies and procedures, emergency plans, and personal attendant care recruiting and management. This committee will also implement quality-measuring tools that will monitor outcomes and assess the success of the program. In addition, the committee has identified a TLU multidisciplinary team. The purpose of the multidisciplinary team will be to review client records, conduct an initial home evaluation, and decide with the client the content of the training program. The team consists of the TLU Supervisor, life skills trainers, rehabilitation engineers, occupational therapists, rehabilitation and peer counselors.

ANTICIPATED OUTCOMES

The TLU is being implemented as a consumer responsive program that will:

1. provide the participants the skills to function as an independent individual
2. provide skills training and assistive technology in a home-simulated environment that includes family participation for the duration of the program
3. provide an environment in which the individual can demonstrate the acquired independent living skills
4. educate the participants regarding their rights and how to advocate for themselves and others.

The TLU program is expected to initiate its services on February of 2000. Future reports will evaluate and describe the outcomes of the TLU program.

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PROMOTING ASSISTIVE TECHNOLOGY (AT) AND HOME MODIFICATION (HM) FOR OLDER ADULTS: A SURVEY OF STATE REHABILITATION AGENCIES

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ABSTRACT

With more older adults with disability, state rehabilitation agency roles in promoting AT and HM are vital. A 1997-98 survey was conducted to determine how they address the AT and HM needs of this age group. Findings include: few programs for these clients despite age-related changes in disability and a lack of relevant staff training. Major barriers are lack of funds, finding competent providers and keeping up with AT changes. Recommendations for additional funding and Tech Act Project roles are suggested.

BACKGROUND

During the past half century, advances in medicine, public health and rehabilitation have increased survivorship of those with disabilities occurring early in life (e.g., polio, spinal cord injury), as well as those whose disability occurs in their 40s, 50s and 60s, a result of age-related chronic conditions (e.g., heart disease, stroke). In 2000, c. 75-85 million Americans will be aging <u>with</u> long-term disability or aging <u>into</u> disability in older adulthood (1). Disability is a normative event in old age; most elders can anticipate an average of 13 years of restricted activity (2). Similarly, the longer a person has had a disability, the more likely he/she is to have secondary conditions leading to functional decline (3). Assistive technology (AT) and home modification (HM [e.g., grab bars, ramps]) can help those with disability to work, live independently and participate fully in the community, often reducing costs and/or the need for personal assistance (4-7).

With the greater importance of AT and HM, increased attention has focused on how policy ensures availability and accessibility (8). Many state programs were developed early in this century (9), but more attention has been paid to federal programs (10). In today's devolutionary climate, state policies become crucial.

Earlier studies found a relative dearth of programs providing rehabilitative services for persons aged 65+ and a lack of devices that respond to the changing physical/functional needs of this age-group over time (11-12). However, this research did not focus on the provision of AT or HM, nor on the middle-aged, and other studies focusing on the actions of State Units on Aging and the Tech Act Projects in this realm lack systematic information across all agencies (13-15). Thus, a study of the extent to which state rehabilitation agencies (RAs) and blind and visually impaired agencies (BVIs) serve the changing AT and HM needs of middle-aged and older adults was undertaken in 1997-1998.

RESEARCH QUESTIONS

1. What agency budget allocations exist for AT and HM? and what is the extent of state funding?
2. To what extent are middle-aged (age 51-60) and older persons a major client group of RAs and BVIs? how knowledgeable are agency staff about AT/HM for these clients? To what extent do these agencies serve and track returning clients who experience changes in their disability level?
3. What are the major barriers to AT/HM access for RAs and BVIs? what are the major issues affecting state provision of AT/HM?

4. To what extent do RAs and BVIs network with other agencies to promote AT/HM access for middle-aged and older adults?
5. What are state strategies for improving access to AT/HM? what has been the impact of the TAPs in improving AT/HM access?

METHODS

In 1997, a questionnaire was designed and modified with help of the Council of State Administrators of Vocational Rehabilitation Agencies (CSAVA). A 49-question, 11-page survey of closed and open ended questions dealing with agency policies and budgets and state-initiated AT/HM policies and programs was mailed to administrators of the 81 RAs and BVIs in 50 states, the District of Columbia and 6 territories.

A total of 52 agencies (64%) responded via mail or fax: 38 RAs (69% of all RAs) and 14 BVIs (54% of all BVIs). They represented 42 states, one territory and the District of Columbia.

RESULTS

Agency budgets: State funding is important, ranging from 10-70% of agency budgets. The average RA budget for AT is 4% of entire agency budget; for HM, 1.6%. For BVIs, AT budgets average 8%; HM, 1.55%.
Clients: for RAs, 13% are age 51-60; 3% are age 65+; for BVIs, 25% are age 51-60; 40% are age 65+. Nearly 40% of RAs serve returning clients with greater disability; only 5% collect data; 64% of BVIs serve this group; only 14% collect data. Routine reassessments are made by 42% of RAs and 58% of BVIs. One-fifth of RA and BVI staffs have training to better serve older clients' AT/HM needs.
Barriers: Both RAs and BVIs cite lack of funds; RAs report limits on non-work-related goals and lack of AT/HM vendors; BVIs, problems with obtaining AT/HM on a timely basis. Barriers to state action include: insufficient funds, lack of qualified personnel and staff training, and keeping current with changing technology.
Networks: Most agencies work with disability organizations, rather than other state agencies. Only 4 RAs participate in the 15 formal state coalitions focused on AT/HM.
State strategies, TAPs: The major state strategy to increase AT/HM is protection (e.g., lemon laws) and advocacy, followed by earmarked funds. The ability of TAPs to promote AT/HM was rated as very effective by RAs (39%) and somewhat effective by BVIs (46%).

DISCUSSION

Overall, older adults, especially those with independent living needs, are not well-served by these agencies. AT/HM funding is relatively low, impacting agency priorities in this area. The changing demographics of disability, while partly recognized, have not led to more programs for older adults. Relatively high levels of state funding are encouraging, but states may not be able to do more, especially when seeking to replace Tech Act funds. While the lack of sufficient funds is a major barrier, closer relations with other agencies (SUAs, Medicaid) may help. Information needs (staff training, promoting consumer awareness, lists of AT/HM vendors, evaluations of devices) are a key issue which might be undertaken by the TAPs with the help of other agencies and organizations. The lack of an effective lead agency was mentioned by several agencies.

Other issues relevant to AT/HM access that need to be addressed were mentioned: third party payment, the role of HMOs, changes in Medicare and Medicaid policy, equipment recycling, differing program eligibility standards and finding substitutes for Tech Act funding. The TAPs, working with existing state coalitions or convening appropriate stakeholders, can lead strategy sessions on these issues.

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ASSESSING THE ASSISTIVE TECHNOLOGY NEEDS OF UNDERREPRESENTED CALIFORNIANS

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Abstract

In 1998-99, the Alliance for Technology Access statewide assessment of the needs and uses of assistive technology among traditionally underrepresented groups in California. Research questions included (1) what is the prevalence of disability and need and use of assistive technology? (2) what barriers impede access to assistive technology? and (3) what organizational approaches have been successful in improving access to assistive technology among underserved populations? Quantitative and qualitative methods were used with different samples. Findings addressed the prevalence of disability, the use and need for assistive technology in California, barriers to assistive technology funding and services, and the need for public information and systems change.

BACKGROUND

This paper presents the findings of statewide assessments of the needs and uses of assistive technology among Californians of all ages with disabilities. The study was conducted during late 1998 and early 1999 with funds from the California Endowment. The project team consisted of the Alliance for Technology Access, InfoUse, and several consultants and volunteers (see acknolwedgements). The needs assessment addressed the assistive technology needs of all people with disabilities, reflecting geographic, racial, and economic diversity of California including infants, children, youth, working age adults, and seniors, people of color and diverse cultures, people with low education levels; and people living in rural areas including migrant and seasonal farmworkers.

RESEARCH QUESTIONS

- What is the prevalence of disability and need and use of assistive technology?
- What barriers impede access to assistive technology among underserved groups according to consumers and service providers? Related questions include:
- What organizational models, practices, resources, and linkages have been successful in improving access to assistive technology among underserved populations?

METHODS

- Review of published data from national prevalence studies such as the Census, Survey of Income and Program Participation, and the National Health Interview Survey, as well as non-national samples to identify need and use of assistive technology in special populations; Sixteen focus groups comprised of consumers representing a cross section of underserved populations in California and front-line providers such as librarians, teachers, AT service providers, and public and private human service professionals;

- Key informant interviews with key leaders in the disability, technology, and underrepresented communities; and
- Interviews with "best practice" leaders across the United States, including state Tech Act directors, as well as RESNA and P & A staff.

RESULTS

Prevalence of Disability, Use of Assistive Technology, and Need for Assistive Technology in California

- 6.6. million Californians have a disability
- About 1.7 million Californians use some kind of assistive technology.
- Mobility devices are the most frequently utilized devices, estimated to be used by more than 800,000 Californians.
- Special populations in California may increase the rate of unmet need in the state.
- People with certain disabilities, notably cognitive impairments, have less access to assistive technology than others and may need much more instruction and support to use it.

Funding for Assistive Technology

Participants reported that lack of funding options to help people purchase assistive technology are exacerbated by:

- A fragmented, overly bureaucratized, underfunded system of public funding sources, and inaccessible private sources.
- High interest rates, rigid eligibility criteria, and harsh repayment schedules in the few available funding programs in California.

Services

- While many assistive technology services are available, participants in our focus groups were confused about how and where to begin a search for assistive technology.
- Californians with disabilities need reliable sources of information regarding what kinds of technology are available, and where to go for assistance in selecting, acquiring and learning how to use the products.
- Organizations and technology service providers are often unaware of other assistive technology resources available in their communities.

- "One-stop shops" are needed for their community in order to test different products, and to borrow and receive training and support in using them.
- Information and services need to be culturally sensitive and available in multiple languages.

Training

- The demand for trained assistive technology service providers far outstrips the supply.
- Consumers want educators, health, and rehabilitation professionals that are better training.
- Not enough training opportunities are available for educators, community-based assistive technology specialists, health professionals, and others.
- While some assistive technology training programs, including certifications, are emerging, there is no comprehensive approach to the wide array of training needs in California.

Systems Change

- Built-in inefficiencies, disincentives, lengthy time delays, restrictive eligibility requirements with respect to disability, age, and income, as well as inadequate funding plague state agencies and other public entities that are mandated to serve people with disabilities in the area of assistive technology.
- Public and private health insurance plans have overly restrictive and antiquated definitions of assistive technology based on medical necessity criteria that do not embrace maintaining and improving independence, maximizing functional capability, and improving quality of life.

DISCUSSION

These results are consistent with congressional findings in the Assistive Technology Act of 1998 and provide rich material for inproving access to assistive technology in California. The Alliance for Technology Access believes that access to technology is the gateway into the twenty-first century for jobs, education, and information. We must ensure that people with disabilities can pass through that gateway. The findings and recommendations of this study have the potential to open the world of opportunity for Californians with disabilities – in their communities, in their languages, and on their terms.

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PUBLIC POLICY AS RELATED TO DISABILITY AND REHABILITATION: IS IT TIME FOR A NEW PARADIGM?

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Abstract

Currently, it is hard to discern what specific rationale underpins public policy regarding disability and rehabilitation. There seems to be lack of a consistent or fair model that determines how resources are allocated. This paper identifies the major factors that influence the present system, and suggests a different approach to making decisions about allocation of resources. The purposes of this paper are to promote discussion among those on the front line of rehabilitation and propose a different approach to determining how resources should be appropriated.

Background

Public policy culminates in decisions regarding allocation of governmental resources. In today's world resources are almost always translated into funding, meaning money. It behooves all citizens to know exactly what determinants influence the decisions–making processes, because after all it is everyone's' resources that are being allotted.

It is especially vital for those who are interested in rehabilitation to understand what dictates public policy because much of what happens in this sphere is directly related to monies set aside for a designated disabled cohort. Because of the increase in percentage and number of older Americans and the explosion of new technology to help those elderly who because of chronic illness are more likely to need assistive devices, an examination of what does and what should influences funding is critical.

If the past funding and regulating related to people with disability is any indication of what the future may hold, those trying to predicate what will happen are in trouble. To briefly consider two examples of results of public policy vis-à-vis the disabled, (a) the blind receive an extra deduction on their federal income tax; and (b) those with end-stage renal disease receive government-compensated care.

Voltaire teased his audiences with the conceit that this is the best of the best of all possible worlds. In a perfect world, it would seem that all citizens should receive benefits related to their needs. However, Voltaire knew, as any thinking modern-day citizen knows, that we do not live in the best of all worlds. It is not a perfect world. Resources are not infinite, but rather quite finite, and one might, if not should, ask hard questions regarding how those resources are spent. To return to the examples, why do the blind deserve another $1050 on April 15, but the deaf don't? Why do those with kidney failure get their treatments totally subsidized, but not those with diseased livers? As almost every one knows it has nothing to do with the magnitude or devastation of the disability, nor the worthiness of the afflicted, but rather with politics.

Politics

Politics is defined as a way of influencing what should be the goals and the subsequent course of action deciding how resources should be distributed. In other words, politics is part of the process that determines policy. Politics is not a neutral term. Politics denotes competing and conflicting values and views. Different points of view are the result of many things.

Vested interests, compassion, and public opinions are concepts that many times influence the politics of policy formulation, especially in terms of the disabled. These concepts are interwoven with the political process. Frequently, vested interests are represented by lobbying.

Lobbying can involve either everyday citizens affected by the specific condition or hired hands. Compassion usually gets translated with an emotional appeal, for instance, legislation by horror story. Public opinion is shaped by many things—stories from the media, individual experiences, advertising and marketing, as well as societal trends. To turn from vested points of view to looking at values, one assumes that principles should be involved.

Principles

Principles, according to the Oxford dictionary, are "truth or law at the basis of reasoning or action". The principles underlying politics may be lofty or base.

Lofty ones maybe rooted in ideas of social justice. Even in discussing social justice, competing and conflicting values loom. Should policy be based on egalitarianism wherein everyone is treated the same; or should distributive justice be given greater importance whereby vulnerable populations deserve more; or should the idea of the greatest good for the greatest number, the major tenet of utilitarianism dictate the thrust. As a society, we have never decided which theory of justice should have the most weight.

To turn from lofty concepts to those more base or malignant, two prevalent ones come to mind, specifically pride and greed. Pride might result in being considered power-hungry. One instance of the power/pride connection is exemplified by politicians' quests for staying in office. Another can be seen in the case where organizations devoted to the disable, recognize that one condition has been alleviated, and rather than closing up shop, that organization seeks to represent another condition, perhaps as a matter of pride. Money is inherent in greed. Campaign finance reform has failed. Money influences elections, issues, and public policy. Money talks and people listen.

What has become a major talking point is that costs associated with rehabilitation have grown at a phenomenal rate. This rise has led policy makers to debate principles such as whether care for the disabled is a right or a privilege. This debate has been center stage in looking at what constitutes the common good. Perhaps no where is this seen as more influential than in policy surrounding the financing of care for vulnerable populations. Is the benefit worth the price?

Price

Recently, the rallying cry for delivery of all services has been "cost containment". As every budding economist knows, price is not the same as cost. One of the most vital aspects of economic theory is that of opportunity cost. Opportunity cost means that certain goods and services "are forgone in order to obtain something else"(1). In other words, if one spends money someplace, that same money cannot be spent for something else—because it's gone. So too, if a professional spend time engaged in one activity, he/she cannot spend that same time doing something else.

Rehabilitation and assistive technologies have been scrutinized based on a cost-benefit analysis. But many times the benefit has not been scrutinized as to necessity as much as desirability. This is the heart of the matter. Perhaps what is desirable for one specific cohort is not good for the whole society. How is this decision about what is good to be made?

New Paradigm

Plato in quoting Socrates declared that an unexamined life is not worth living. To extend that thinking to the topic at hand---unexamined policies are not worth having. As a nation, legislators, regulators, and citizens must examine the policies related to the disabled. That examination must include revisiting the following questions:

- How is disability defined? (2)
- What policies are currently in place?
- What was the rationale behind these policies? and, perhaps most important,
- Is that rationale still valid?

Answering these questions is difficult, as other equally probing questions result, such as:

- Is there not danger of going backward in time to when the disabled were invisible and/or mistreated?
- Is there not a chance that profound beliefs as well as livelihoods might be compromised?

Even with these dangers, one must admit that the present system is not fair. Why one group receives more resources than another should not be based on skill in lobbying or promise of votes.

There are three major thrusts in proposing a new paradigm. First there must be an open discussion on current laws, regulations, and funding related to disability. A public interest group without ties to any specific collation or rights groups should do this. Second, once this discussion takes place, a decision must be made about what, and subsequently who, should receive resources. This decision can be through democratic processes. An excellent prototype is the methodology used by the state of Oregon in deciding which medical procedures and diseases should be subsidized by the citizens. The third thrust, and especially crucial to this process is dissemination of evidence-based findings related to disability. Words like "effective" and "beneficial" must supercede words like "it would be nice" or "it might help". In other words, approaches to allotting of resources must be based on research findings that these approaches work, rather than on playing politics. Rarely do new innovations live up to cost-saving expectations (3).

Conclusion

In conclusion, the purpose of this paper has been two-fold (a) to provoke discussion among those on the front line of rehabilitation (because if this group doesn't do it, one can be assured that someone else will) and (b) propose a different approach to deciding on how resources be allocated. Certainly those who have lasted throughout this presentation have already been provoked, now it becomes most important to engage in discussion about the issues raised.

It is hoped that the discussion might center on a somewhat different approach than historically or traditionally has been used as the basis for determining policy. At the risk of being identified as terminally naive, a new paradigm has been proposed on which to base decisions. Is it perfect? Of course not, nothing is, but it would seem that a paradigm based not on mere politics, but rather on enlightened outcome measures would be fairer and more rationale.

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ACCESSING ASSISTIVE TECHNOLOGY

Strategies to Enhance Access to Assistive Technology in Pennsylvania

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ABSTRACT

The Pennsylvania Office of Vocational Rehabilitation (OVR) in partnership with the University of Pittsburgh Medical Center and the Department of Rehabilitation Science and Technology developed a strategic plan to enhance access to assistive technology (AT) services and devices in Pennsylvania (PA). This paper describes the strategies that were identified, as well as the progress and challenges found in the implementation of these strategies.

INTRODUCTION

The Hiram G. Andrews Center (HGAC) of the Pennsylvania Office of Vocational Rehabilitation is a comprehensive vocational rehabilitation facility. Services provided include vocational evaluation, vocational training, residential and transitional living facilities and assistive technology program. To provide a complete program in assistive technology, the HGAC established the Center for Assistive and Rehabilitative Technology (CART) in 1995. CART was implemented as a comprehensive AT service delivery program and also as the hub of the statewide AT program called the CART Network (1). The CART Network is currently under development and is designed to provide AT services to persons with disabilities throughout the state of Pennsylvania (2).

As part of the long-term plan for providing AT services in PA, the HGAC defined several strategies. Initially there were three strategies, a) provision of in-house AT services to HGAC clients, b) provision of in-house AT services to non-OVR clients and c) provision of statewide AT services to OVR clients. Then, in 1998, through an initiative of the Pennsylvania Tech-Act Project, Pennsylvania established the Pennsylvania Assistive Technology Lending Library (PA-AT-LL). The operation of the PA-AT-LL became part of the CART Network. Recognizing its potential to provide access to assistive devices, the PA-AT-LL was adopted as the fourth strategy to enhance access to AT devices for persons with disabilities in Pennsylvania. This paper describes each of the strategies to provide AT services and their contribution to the CART Network.

STRATEGIES

<u>In-house AT Services to HGAC Clients</u>

The CART was planned and implemented as a comprehensive provider of AT services. The main purpose of establishing the CART was to provide the full spectrum of AT services to clients that attend the vocational evaluation and training at the HGAC. The full spectrum of AT services includes evaluation and demonstration of devices for persons with physical, sensorial and intellectual impairments. In addition, the CART was designed as a teaching laboratory to provide AT short-term training to OVR counselors and other health professionals. Finally, the CART also functions as a demonstration lab where clients, professionals and OVR authorities can learn and experience the use and benefits of AT.

In order to build a network of AT service providers, two additional elements were required. First the need to provide regional services outside the OVR structure, and second, the need to provide AT services throughout the state.

In-house AT services to non-OVR clients
In order to expand the services of CART and make them regionally available to individuals not eligible for services under the OVR system, CART negotiated a contract with a local accredited health care provider named Conemaugh Health System (CHS). The contract with CHS made possible the provision of AT services to non-OVR clients by registering them as outpatients of the CHS and receiving AT evaluation services by CART Staff. CHS is physically located within the same building as the CART program.

Provision of Statewide AT Services to OVR Clients
HGAC, a state operated rehabilitation facility, serves clients from all parts of the state. Therefore, the CART program addresses the needs of persons with disabilities that reside throughout the state. To accomplish this task, three service delivery models are being implemented in addition to the services provided by the CART. The first addresses the provision of services for clients residing in large cities. The plan is to establish a contractual arrangement with a large AT service provider to act as a satellite of the CART program.

The second service delivery model is for clients residing in smaller cities in the state. In this case, engineering and therapy teams, trained at CART, will reside within the smaller cities. These teams will function as coordinator of services with existing local AT service providers. In addition, they will coordinate the provision of AT services at CART when needed. The overall purpose of this modality of service delivery is to extend the presence of the CART where people live, work and need AT services.

The third model is designed to address the AT needs of clients residing in rural areas. To implement this model, the use of video-conference equipment is presently being tried. The intent is to use video conference equipment as a tool to screen and conduct basic AT evaluation services. Video-conference will allow CART team members to be in contact with the resources available at CART or any of the teams residing in large or small cities. At present, the three models are being implemented and future reports will present the lessons learned.

Pennsylvania AT Lending Library (PA-AT-LL)
The fourth and final strategy added in 1998 consisted of establishing the Pennsylvania's Assistive Technology Lending Library. The PA-AT-LL evolved from the experiences of running modest AT lending programs by The Institute on Disabilities from Temple University and the CART program. The transformation from these two small programs to the larger PA-AT-LL took place through the successful efforts of The Institute on Disabilities to include the PA-AT_LL as an initiative in the state's disability agenda. After the initiative was approved, the PA-AT-LL was established at HGAC and provides AT loan services to residents of PA.

RESULTS
The above mentioned strategies have produced successful outcomes. The In-house AT Services to OVR Clients has provided services to more than 1100 clients in the last three years. The In-house

AT Services to non-OVR clients has steadily grown from to 24 clients during the first year to 139 clients during its third year of operation.

The provision of the statewide AT services to OVR clients continues to be developed. Presently, as part of the large city model, services are being provided to clients residing in Western Pennsylvania at the Center for Assistive Technology, located in Pittsburgh, PA. A new large-city provider is being sought to deliver AT services to clients residing in Eastern Pennsylvania. During 1999, 30 evaluations of clients residing in rural areas were completed using video-conference equipment. Preliminary results indicate that this model requires a long learning curve but promises to be an efficient modality of delivering AT services to rural areas.

The Pennsylvania AT Lending Library services are growing steadily. Devices are loaned for a period of two to six weeks. There is no cost to the lender of the equipment. The devices can be requested through numerous PA-AT-LL branches located throughout the state. The PA-AT-LL is planning to have its inventory published on the Internet to facilitate information regarding availability of the devices. During its first year of operation, the library received 1430 requests and shipped 2381 devices.

DISCUSSION

Each of the implemented strategies has presented challenging situations. The provision of in-house AT services to OVR clients required the development of procedures and quality measures not previously used in the OVR system. The provision of in-house AT services to non VR clients demanded the establishing of formal partnerships with other heath care providers before AT services could be delivered. The most challenging situation has been the implementing of the statewide system. Some of the challenges faced include the administrative coordination of multiple agencies and service providers, the different level of expertise of the service providers, the lack of standardized quality measures and the wide disparity in the availability of quality and timely services. However, these experiences were very helpful in the establishing of the library and other auxiliary AT programs within the HGAC. The PA-AT-LL became the ideal model of statewide operation and integration in which devices are loaned throughout PA to persons with disabilities regardless of their age, disability and potential funding source.

The implementation of these strategies will continue until all Pennsylvanians with disabilities gain access to comprehensive, integrated, personal, quality and timely AT services regardless of where the clients choose to live.

ACKNOWLEDGEMENT

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VOCATIONAL REHABILITATION COUNSELORS AS ASSISTIVE TECHNOLOGY CUSTOMERS: INFLUENCES ON THE INTEGRATION OF AT SERVICES

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ABSTRACT

The statewide Assistive Work Technology (AWT) Program of the Georgia Division of Rehabilitation Services is in the process of developing a system for continuously improving programmatic and service delivery outcomes. A research methodology was established to determine what factors influence the level of integration of AT into VR cases, the expectations counselors have of the service and its providers, and the satisfaction they experience with the results. The data resulting from this research will have implications for improving the implementation of AT in the VR process, thereby helping ensure more efficient processes and better employment outcomes for the consumer.

BACKGROUND

A major role of the VR counselor is to help plan and organize the provision of services needed to assist an individual with a disability to work. This professional is thus arguably the most influential stakeholder involved in the delivery of AT services. Flynn and Clark (1995) noted that counselors are by far the largest source of referrals for consumers in the VR systems in America, and advocated increased referrals from counselors to enhance access to technology services within VR systems. Meeting the needs and expectations of the VR counselor is thus seen as one of the most important areas of effort.

Unfortunately, the level of integration of AT into VR programs, and the cognizance of counselors as to the potential benefits of this service for their customers is inconsistent at best. Langton (1991) noted that "Case management staff often do not have a sufficient understanding of when or how technology should be utilized." This can lead to inappropriate determinations of ineligibility, unnecessary counseling of consumers to modify their vocational goals, waste of resources on inappropriate services or equipment, and sub-optimal employment of consumers, among other detrimental outcomes.

RESEARCH QUESTIONS

There are three over-arching questions of interest in this study: 1. What factors, to what extent, determine satisfaction on the part of the VR counselor with AWT; 2. How do these measures vary among counselors (i.e. what differences among counselors affect the level of satisfaction due to each factor); and 3. What factors (including satisfaction) influence or disinfluence the utilization of AWT services by counselors.

METHODS

A review of the rehabilitation literature revealed very little pertinent information regarding counselor behavior with respect to the utilization of assistive technology. Flynn and Clark (1995) reported measures of AT service utilization in VR programs across the nation, and described how those services were implemented. No references were found , however, that model this behavior in terms of factors that impact counselor decisions to request AT services or their perceptions regarding the outcomes of the services.

A multi-stage information gathering process was begun in order to establish the framework for a model of counselor behavior. The first stage involved interviewing a small number of VR counselors, having a spectrum of educational, caseload, experiential, and AT referral histories. This was intended to provide a foundation of data that could serve to refine the development of hypotheses important in developing our model. The results, together with qualitative observation of counselor behavior over a number of years, lead to an initial model describing factors that influence counselor behavior with respect to AT services. In this model, we hypothesize that referral rate is positively influenced by service outcomes, identified need for the service, and DRS policies, and negatively influence by the counselor's initial expectations. This last is hypothesized to result from the likelihood of high initial expectations to not be met (resulting in reduced satisfaction) and for low expectations to be exceeded (resulting in increased satisfaction). Outcomes of interest to counselors are expected to include: case outcome (26 closure or resulting advance in case status), counselor satisfaction, client satisfaction, and referral source satisfaction. The counselor's ability to identify a need for AT services is expected to depend on intrinsic counselor characteristics (education, VR experience, caseload, and similarity of case situation to previous cases requiring AT). Factors that influence counselor expectations are anticipated to include: counselor education, VR experience, previous disconfirmation of expectations, and the frequency and quality of interactions between counselors and AT providers.

RESULTS

A small focus group of counselors was interviewed to investigate the applicability of these hypotheses from the counselors' perspectives. The results indicated that all of the factors seemed applicable, except DRS policies, which were not seen as a factor in affecting counselor referral behavior. The results also highlighted some unexpected aspects of the interaction between counselors, their clients, and AT providers. Counselors most often described AT outcomes as successful based on consumer satisfaction with the results, rather than merely with the resulting case outcome. In other words, while successful closures are the outcomes by which counselors are evaluated, the results they expect from AT largely include giving their clients improved opportunities and future vocational direction. In addition, a counselor's level of experience in using AT services does not seem to have a strongly positive influence on the counselor's referring behavior, but the lack of such experience seems to negatively influence referrals. Also of interest is the degree of importance given by the counselors to the advice and consultation role played by some AT providers, as well as the improved perceptions they receive from their clients and referrers, simply by bringing AT providers into the team.

The complexity of the interactions among influences on counselor behavior indicates a model of behavior that differs extensively from the various models that emphasize improvement in client clinical outcomes and cost (Minkel, 1996). The need for a new model was reinforced by citations from Linder-Pelz (1982a, 1982b) and Johnson, et al (1993) which indicated that consumer satisfaction with health care providers is 'poorly related to technical effectiveness or professional standards', but is more consistent with perceptions of provider conduct or skill in interpersonal relations, among other qualitative characteristics of the service.

This lead us to expand our literature review to include marketing science research on customer satisfaction and professional level customer interactions in order to seek a more realistic model on which to build. A study of the determinants of consumer satisfaction in business-to-business transactions, done by Patterson, et al (1997), explored a model which seems very consistent with our initial findings. They found that customer satisfaction/dissatisfaction is the largest factor in repurchase decisions. However, the determinants of satisfaction are more complex in technical transactions that are poorly understood by the consumer than in typical retail or low-involvement transactions. Perceptions of performance are indeed major factors in creating client satisfaction, but the direct effects are much smaller than the cumulative effects of disconfirmation (not meeting expectations) and fairness (equitable treatment in the transaction). Furthermore, the novelty, importance, and complexity of the decision to request services have an overwhelming impact on all three of the major determinants of satisfaction.

DISCUSSION

What has been described in this paper is merely the outline of a model which will be used to develop some of the outcome measures that will prove meaningful, both clinically and programmatically. We are beginning the process of validating data collection instruments which will be integrated into the AWT service delivery process. The resulting data will be used to refine the validate and refine our model of counselor referral behavior and create a system for continuously improving the outcomes.

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TELEREHABILITATION: CONTINUING CASES AND NEW APPLICATIONS

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Abstract

The purpose of this article is twofold: to describe processes used to design, install and deliver assistive technology (AT) services via telerehabilitation; and second, to add to previous telerehabilitation case studies. Telerehabilitation is defined as the use of telecommunications technology to provide rehabilitation and long-term support to people with disabilities. A brief background is presented regarding historical needs for telerehabilitation to complement existing AT services, and thereby extend the continuum of health care services into the clients' home communities.

Background

Clinicians as Shepherd Center have used telemedicine or telerehabilitation to provide post-discharge support for patients with catastrophic injuries for over four years, including spinal cord injury, multiple sclerosis, acquired brain injury and other neurological disorders. Telerehabilitation is proving to be an extremely useful tool to extending clinical expertise into the patients' home communities. It is believed that this will lead to better community reentry, improved quality of life and greater efficiency use of limited healthcare resources (1).

Using, telerehabilitation, delivery of several AT services previously described, includes Alternative and Augmentative Communications (AAC), home modification, computer access and a seating clinic consultation. These were accomplished using low-bandwidth (Plain Old Telephone Service) POTS technology in conjunction with video camera and videophone technology (1). POTS was chosen as the means of delivery, due to limited cost, ease of use and availability.

Due to long distance from specialized clinical care, patients frequently live in medically underserved regions of the country. Telerehabilitation investigations described here addresses problems with availability of Assistive Technology resources, especially adequate AAC training and residential evaluation for home modification. Certain technological limitations have been addressed and newer; novel applications have been implemented with different clients.

Methods

As with all clinical interventions, telerehabilitation applications identify clinical needs first, then appropriate technology. In attempting to find the best application for patients, their families and the clinicians, several technologies were assembled. In certain applications, low-tech, "off the shelf" solutions, may suffice, rather than hi-tech, engineered solutions, requiring time-consuming testing and re-adjusting of newly developed technology. However, when simple solutions fail, more complicated technological solutions may need to be found. This concurs with current human factors engineering principles (3).

Results

Case 1: <u>"Maria" - EZ Keys training via TeleRehabilitation</u>

Maria is 22 year old Caucasian female and has the neurological movement disorder know as dystonia, specifically spasmodic disphonia, which affects the muscles controlling vocal cords. This condition makes it almost impossible for Maria to speak. In order to regain the ability to communicate verbally, it was recommended that she use the EZ Keys System (Words+ Inc., Lancaster, CA). EZ Keys is a combination software/hardware platform that runs in conjunction with a Microsoft Windows-based laptop personal computer (PC). By interfacing the system through the computer, it "speaks" for the user in an audible computer-synthesized voice. EZ Keys was installed on her PC, however, in order to for

Maria to gain mastery, it required extensive training by a speech-language pathologist (SLP) at Shepherd Center. Because she had to return to her home community some distance from Shepherd Center, she was judged an excellent candidate for telerehabilitation.

Two-way video sessions were conducted between Maria and the SLP using an 8x8 ViaTV VC-50 (Santa Clara, CA). Initial video images of Maria's computer were unacceptable (See figure 1). To counteract this, the computer screen's output was directly connected to the video phone via a "TV-2 Superscan" video scan converter made by ADS (Cerritos, CA). This converted the computer's super video graphics accelerator (SVGA) signal into a standard video signal (called RCA). The video signal was then sent to Shepherd Center via video conferencing. The "direct" electronic image was substantially improved over the optical/video image (See figure 2). Ideal audio was provided for by connecting the video phone to an Ameriphone speaker phone, especially manufactured for use by people with disabilities. While less than perfect, the resulting images and sound were sufficient to train Maria using the EZ Keys system, where she might not have otherwise received AAC training.

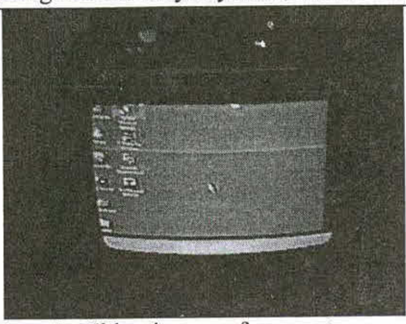


Figure 1: Video image of computer screen.

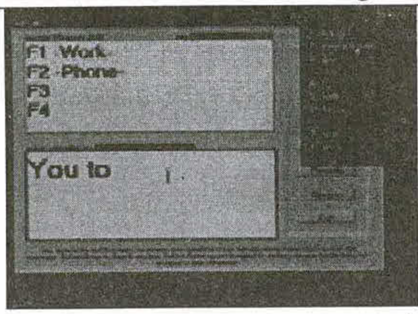


Figure 2: Computer screen via "direct" wiring.

Case 2: "Sarah"- Speech recognition training via Telerehabilitation

Sarah is a 42 year old Caucasian who has tetraplegia due to a C3-4 spinal cord injury, which occurred 15 years ago. She was recently re-admitted for rehabilitation after incurring an anoxic brain injury due to prolonged respiratory failure. She has outstanding and cognitive impairments and behavioral and psychosocial issues due to the brain injury. Sarah has demonstrated an interest and ability in using her PC for correspondences, internet access and other functions. In order to accomplish this her computer was adapted to use Dragon System's Naturally Speaking™ voice-speech recognition system which runs under Microsoft Windows. This system, when activated, turns the PC into a personal dictation system; it recognizes speech and types in on the screen. The system requires "training", in that it must painstakingly learn one's voice and personal vocabulary. This may take days to program one's voice, and many weeks to learn. Sarah and her family trained via telerehabilitation using the following technology: Aviva 1010 Personal Telehealth Unit (American Telecare, Eden Prairie, MN); PC; TView Gold (Focus Enhancements, Wilmington, MA) video scan converter.

Training via telerehabilitation was difficult with Sarah, at first, for several reasons. First, Naturally Speaking runs in the Windows platform; she relied on her mother who was not computer literate to set up the computer. Second, fonts and screen image size on her computer had to be simplified, in order to transmit images to Shepherd Center. These were accomplished, long distance, with patience. As with all tele-interventions, time needed to be allotted to optimize the system. At the time of this writing, biweekly training on Naturally Speaking continues.

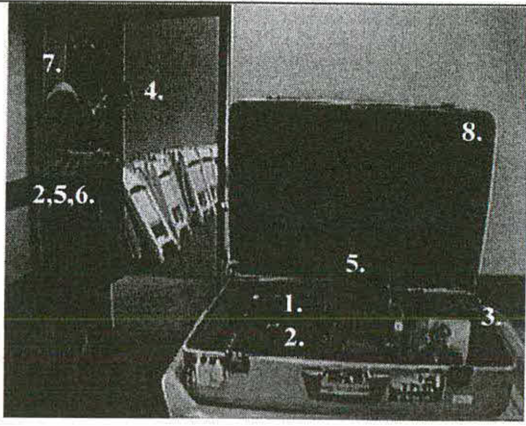
Case 3. "Wireless" Home evaluation for modification

Another application of AT services delivered via telerehabilitation includes home evaluation for modification to increase accessibility for persons with disabilities. After discharge from rehabilitation, our clients may need to have their homes evaluated for modification in order to move freely about the home, in a wheelchair, for example. Often times technical staff and/or an occupational therapist (OT) may need to travel great distances to evaluate the home. Telerehabilitation attempts to bridge these distances and thereby reduce cost by evaluating homes long-distance. A portable system for home use has been comprised to allow for "wireless" mobility in the client's home. Unlike previous telerehabilitation visits, the clinicians at Shepherd Center desire to see the interior of the client's home independently of telephone and video equipment and still maintain audio and visual communication.

A portable video system was comprised using the following technology (figure 3):

A. Home "Base Station"
1. 8x8 Inc.VC-50 video phone
2. Vtech 900 MHz cordless speaker phone.
3. Sony XL-700 portable LCD video monitor.

A. Portable wireless unit
1. Canon ES-970A camcorder.
2. Wireless Room-to-Room Audio Video Sender, Radio Shack (2.4 GHz)
3. PowerSonic lead-acid battery to power Video Sender
4. Microphone headset attached to phone.
5. Suitcase
6. Optional: video tripod for image stability.



The wireless 900 MHz digital telephone and the 2.4 GHz video sender transmit audio and video signals with out wires. Both are off the shelf technologies, which transmit signals back to the clinician pictured above. Technically, results were, however, further work must still be done to make the system more robust.

Discussion

Historical and perceptual differences exist between technological and clinical staff. Telerehabilitation can address administrative challenges, specifically, reimbursement. Since healthcare is in a state of flux, it is believed that technology (in this case telerehabilitation) may extend the continuum of care and help mobilize and empower allied healthcare professions. Then, so too, might assistive technology community embrace telerehabilitation as a means of extending care, ensuring follow-up and improving patient follow-up. It is believed that ultimately, managed care may provide revenue for telerehabilitation.

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FACULTY SUPPORT: REMOVING THE BARRIERS TO EFFECTIVE DISTANCE EDUCATION IN ASSISTIVE TECHNOLOGY

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ABSTRACT

Because of the remoteness of their setting, the hectic pace of their schedules, or other complicating factors, assistive technology professionals often have difficulty in finding appropriate educational opportunities for professional development and continuing education. Distance education in assistive technology can be an effective solution. A year-long analysis of local practice and scholarly literature on distance education revealed six major barriers to effective preservice and inservice distance education in assistive technology. One of the most important strategies for removing many of these barriers resides in an appropriately-designed faculty support system. This paper summarizes the attributes of such a system.

BACKGROUND

Definitions. *Distance Education* is a system and a process for providing instruction at a distance. Distance education occurs when (a) an instructor and student(s) are physically separated, (b) an educational institution is involved in the planning of curricula and the provision of student support services, and (c) educational media (i.e., voice, video, data, or print) are used to unite teacher and student and to carry course content across the instructional gap. Distance education includes *distance teaching*, the teacher's role in the process, and *distance learning*, the student's role in the process -- and the desired outcome of distance education (1, 2, 3, 4).

Distance Education Formats. Technology offers an institution of higher education (IHE) and its faculty many options for providing education at a distance. This domain can be viewed in terms of the nature of the channels by which information is exchanged between instructor and student (1, 2, 3). From this perspective, there are six major formats for distance education: (a) computer-mediated, sometimes referred to as *computer conference courses* (real time or delayed) and the latest variation, *web-based courses*.(b) 2-way video/2-way audio, sometimes referred to as *2-way interactive video courses*. (c) 1-way video/2-way audio, sometimes referred to as *satellite courses*. (d) 1-way video/1-way audio, sometimes referred to as *videotape courses*. (e) 0-way video/2-way audio, sometimes referred to as *audio conference courses*. (f) 2-way print, sometimes referred to as *correspondence courses*. In practice, each of these formats often includes a multitude of subsidiary formats to support the teacher-student exchange of information, e.g., fax, telephone, e-mail, "snail" mail.

STATEMENT OF THE PROBLEM

The provision of assistive technology services requires practitioners with the proper knowledge, skills, and dispositions. An important initiative undertaken in recent years by RESNA and other major professional organizations involves specifying technology-related standards and validating professionals' skills. The availability of appropriate professional development opportunities to acquire the knowledge and skills required for credentials and advanced degrees, especially for service providers in rural areas, however, can be problematic. Distance education has great potential to assist in the resolution of this problem (2, 3). Research on learning effectiveness reveals that, *when distance education is designed, implemented, and administered properly*, there are no significant differences between distance learning and learning acquired through more traditional methods -- sometimes distance learning is even superior (5). This finding, combined with its advantages in reducing the major obstacles imposed by location, time, culture, language, and disability, should provide strong impetus for increased use of distance education by IHEs to deliver assistive technology instruction to preservice and inservice professionals. Our study has revealed, however, that six major barriers exist to the provision of these opportunities (described in detail in 1, 3).

These barriers are: (i) negative attitudes about distance education among faculty members and academic administrators (6, 7), (ii) a "change-the-student-rather-than-the-system" orientation by the administration in resolving problems of access to education (7, 8), (iii) low interdependence among faculty members within and across departments and systemic disincentives to collaborate to solve problems, deliver programs, and share expertise (7), (iv) increased sensitivity and vulnerability to criticism by administrators and faculty members that inhibit their willingness to embrace, or even consider, distance education (7, 8), (v) administrative policies that frequently place distance education activities outside the central, core fabric of a university's academic programs (3, 4), and (vi) political and economic pressures that seduce some administrators and faculty to embrace a particular format of distance education without knowledge of the factors necessary to insure its efficacy (1, 9).

APPROACH

The approach in this paper is to summarize one of the most important strategies to overcoming many of the barriers to the successful preparation of preservice and inservice professionals in assistive technology via distance education: the creation of a system to provide faculty support in the development and delivery effective distance teaching. This discussion is based on a year-long study that included a review of the scholarly literature and analysis of local practice that was conducted by an interdisciplinary task force at the University of Delaware. To meet the objective of effective distance teaching, we recommend that IHEs implement the following programs and activities.

Raising Faculty Awareness. This category includes strategies that deal with raising the awareness and dispelling the misconceptions of faculty and administrators about distance education.

a. To dispel any misconceptions and misinformation that exist on campus about the "newness" and the instructional effectiveness of distance education, make available to faculty members, departmental chairpersons, academic directors, and college deans research-to-practice summaries of the scholarly literature on distance education.

b. To increase awareness of the university's distance education facilities and demonstrate their ease of operation, support the chairpersons of each academic unit in conducting faculty meetings inside an instructional television (ITV) two-way interactive classroom, or between two ITV classrooms via an ITV link, while also employing some assistive technologies.

c. To facilitate the emergence of a community of shared expertise and to provide live models of distance teaching, create and publicize a directory of faculty members at the university who teach some form of distance education and who have agreed to permit other faculty members to observe their instructional practices.

d. To heighten awareness of distance education on campus, publish a regularly-scheduled column in the teaching center's newsletter that addresses distance education tips, strategies, and creative practices and that highlights in succession each of the different colleges in the university.

e. On the teaching center's web page, provide regular postings of distance education regional, national, and international conferences; of grant competitions relevant to distance education; and of web sites devoted to distance education issues.

f. To heighten awareness of distance education on campus, host a university-wide conference that spotlights exemplary distance teaching practices among the university's faculty.

Developing Teaching Expertise. This category includes strategies that deal with developing and supporting advanced knowledge and skills in distance teaching among the faculty.

g. Initiate and develop a mentoring program that links experienced distance instructors with interested novices. This represents a powerful method for enhancing faculty confidence and skills.

h. Offer regularly-scheduled workshops that provide hands-on training on distance education instructional design, teaching methods, and management skills within each academic unit each year.

i. To provide faculty accessible models, establish a resource library of videotapes of exemplary distance teachers across a variety of disciplines and links to exemplary web-based courses.

j. Support informal faculty-to-faculty interaction and networking for collective sharing of expertise, cooperative learning, and problem solving at the university via a campus "teleteaching user group" and listserv.

k. To minimize disincentives to distance teaching and to maximize the effective use of distance technology, institute a system that provides "on-call" technical support services and equipment to faculty and staff (e.g., hardware and software troubleshooting).

Providing Incentives and Rewards. This category includes strategies that deal with establishing in the administrative system of the IHE rewards for acquiring knowledge and skills in distance teaching.

l. Host an annual internal campus grant competition specifically targeted toward the development of new distance education course offerings to encourage novice faculty members and to support experienced faculty members in undertaking especially creative and labor-intensive applications.

m. As manifestation of the institutional value ascribed to excellence in distance teaching, sponsor annual distance teaching awards, including monetary honoraria, that are awarded within each department or college.

n. To facilitate a culture of innovation, sponsor a caucus for full professors, departmental chairpersons, college deans, and other leaders who are influential in defining the core values of the institution on the importance of distance education to the future viability of the department and the institution, the relevance of distance education to the promotion and tenure of junior faculty, and the relevance of distance education to the annual performance evaluations of all faculty.

DISCUSSION

In this era of educational reform and heightened accountability, the use of procedures to validate the competence of assistive technology professionals is gaining momentum. This movement requires availability of educational opportunities to acquire the necessary assistive technology expertise and access to those opportunities. Distance education has great potential to augment this access. To realize the benefits of distance education, however, faculty will need to be skilled and creative practitioners of distance teaching. Attitudinal, administrative, and political barriers to this objective are deeply-entrenched. Our analysis has shown that an effective faculty support system within a supportive administrative infrastructure is a key factor in overcoming those barriers. The effects of such systems will be success in distance education in assistive technology and, ultimately, a more skilled and effective body of assistive technology professionals. Future reports will highlight the importance of student support systems and other major strategies to systematically address those barriers.

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DEVELOPMENT OF ONLINE COURSEWARE AND SUPPORT TECHNOLOGY

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ABSTRACT

A service model for support of professionals working with persons with disabilities combines online learning with Internet courses and direct interaction by videoconferencing. Two projects are reported upon. In the first project a set of online learning modules is being developed and tested. These are aimed at teachers of students who are in the process of recovering from Acquired Brain Injury (ABI). The second project develops an online version of the RESNA Fundamentals Course on Electronic Aids for Daily Living (EADL). In addition to following these courses, teachers in the community can interact with resource teachers at the Centre via voice, video or data transmissions.

PROJECT DESCRIPTION

We have used videoconferencing for about three years, for clinical and educational purposes. This experience has shown us the strength and weaknesses of the technology (1). We believe that a combination of videoconferencing for direct interactions (with the capacity for document exchange and file-manipulation) on the one hand, and Internet-based course delivery on the other, are ideal for situations in which community members require support and/or information. This combined use of delivery vehicles both synchronous (videoconferencing) and asynchronous (Internet courseware), is currently the optimal way to provide long term and economical consultation and support to consumers, parents, teachers, and other professionals.

The focus of the first project is to assist students with ABI and teachers working with these students in their home schools and communities. As many as 70% of students with ABI fail after returning to their home schools (2). These students require special support to reintegrate into the environment from which they were traumatically removed. The knowledge required to effect this reintegration and to introduce new ways of learning is available in some locations but is not generally known to all teachers who are called upon to teach students with severe ABI.

This project develops and evaluates a support infrastructure and a World-Wide Web (WWW) based course. The support network allows live two-way interaction between students and/or teachers in the community and resource teachers at our Centre. The on-line course content will be implemented in several modules, or workshops. Initially it will be presented on the internationally renowned special education web site of the Special Needs Opportunity Window (SNOW) project (http://snow.utoronto.ca). After the courseware has been tested it will be transferred and incorporated into the online curriculum of Cambrian College of Applied Arts and Technology in Sudbury (ON). We will evaluate the ABI courseware with participating teachers and professionals on the WWW, and will evaluate the support structure for its effectiveness using 18 schools.

In a companion project, funded by Human Resources Development Canada, we are working with Cambrian College, Sudbury, RESNA, and Children's Treatment Centres to implement on-line modules of the RESNA Fundamentals course on EADL. This project explores new ways of implementing on-line learning materials that deliver information and develop skills related to EADL and AT devices. These materials will be tested with a limited sample of learners but has the potential to become available to a widely dispersed population of learners who may be clients, parents, teachers, and practicing professionals. Once this material becomes available it will increase the economy (2) and accessibility (3) of this information

METHOD

For the ABI project, a brief survey was developed and distributed by facsimile. Seventy-five surveys were sent to six different school boards and twenty-two responses were received within the first two weeks. Out of these early responses the majority of staff requested support materials and informational resources in the areas and in order of importance as listed in Table 1.

Impact of ABI on Learning (4.90)	Background Knowledge of ABI (4.63)
Educational Progr. Modifications (4.10)	Social & Emotional Issues (3.84)
Behavioural Problems (3.58)	Transitional Planning (3.47)
Assessment Methods (3.20)	Information about the Brain (3.00)
Glossary of ABI related terms (2.89)	Models of Service Delivery (2.79)
Community Support (2.79)	Case Studies (2.47)

Table 1: Average ranking (out of 5) for 14 potential resource topics listed in the survey

We performed an exhaustive search of the World-Wide Web, bookmarked about 300 sites and classified the sites as follows:

- Academic/Research: sites with primarily a research or academic (i.e. non-applied) orientation
- Clinical/Rehabilitation: sites from clinical or rehabilitation programs;
- Personal: sites that were developed by relatives (spouses) or friends of persons with ABI;
- Associations and Organizations; and
- Listserves and Newsgroups: bulletin boards for people to ask and answer questions

We developed content for eleven ABI course modules: one introductory workshop and ten in-depth workshops. We will implement the EADL courses in collaboration with Cambrian College. The College has in turn agreed to offer as part of their on-line curriculum the ABI course that we are developing and testing with support from the Ontario Neurotrauma Foundation. Each course is authored by a team of experts, reviewed by an expert panel and prepared for online delivery using a WWW courseware toolset called WebCT (supplied by WebCT, Inc., Peabody, MA).

Videoconferencing support uses a variety of equipment, all of which use the H.320 video telephone standard and ISDN (Integrated Services Data Network) telephone lines to communicate with each other. Equipment at the rehabilitation centre includes: desktop systems for individual consultations; a PictureTel 4000 boardroom system for educational and large conference events; and a PolyCom ViewStation MP, a multipoint system that allows us to simultaneously connect up to four sites. This multipoint unit is useful for teaching or group consultation sessions. The schools are using PictureTel Live 200 and Intel ProShare desktop systems. (The PictureTel and Intel ProShare products are supplied by PictureTel Corp., Andover MA. The ViewStation MP was supplied by Polycom, Inc., San Jose, CA.) Figure 1 shows a three-way call, as seen from one of the desktop units.

RESULTS

Initial results of the first postings of the Introductory ABI Course were positive. Fifty seven persons took the first session of the course and 38 the second. WebCT tracks visits to the pages and results on the built-in tests. Post course survey results were used as formative evaluation to improve the quality and format and presentation of the course. Videoconference have just commenced and evaluations have just started on three pilot sites. EADL course evaluations will start in January 2000.

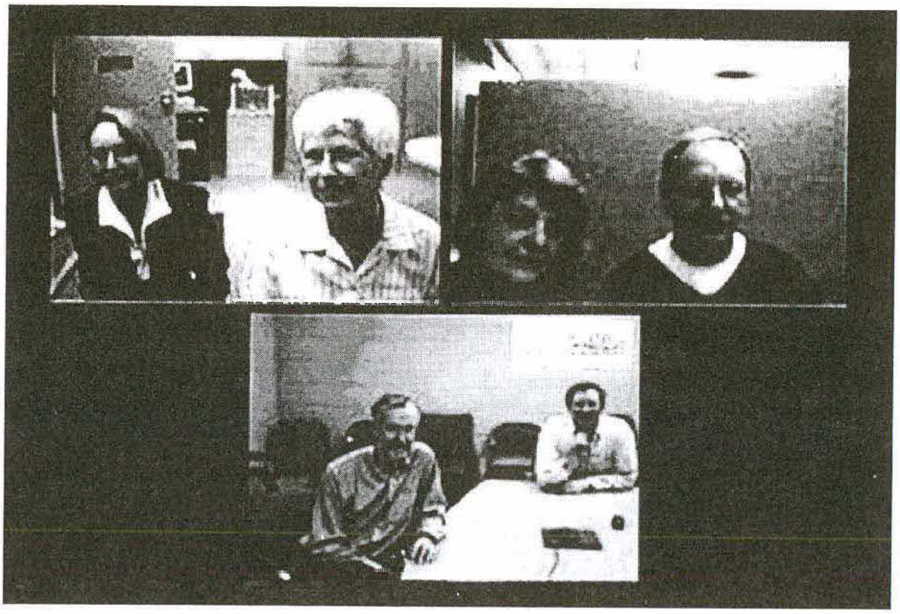

Figure 1: Three-way consultation using videoconferencing

DISCUSSION

This project combines remote consultation via telephone videoconference, and training of community professionals via Internet online courses. The potential for this combination of technologies for rehabilitation services and care is very promising but requires careful development. This gives professionals the ability to consult with clients and colleagues from their desktop or clinic room and at the same time make available relevant and pertinent information and training materials. We believe these abilities can dramatically expand their role, effectiveness, and potential influence in the field. This project will help identify the pitfalls and benefits of this exciting technology.

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PROJECT IMPACT ACTIONS FOR DEVELOPING ACCESSIBLE POST-SECONDARY EDUCATION ENVIRONMENTS

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ABSTRACT

Project IMPACT serves as a national demonstration project to improve access to assistive technology and accessibility of educational technology for students with disabilities of a post-secondary education institution. The project is organized as a collaboration of support services and academic units across an urban campus. The team is implementing various strategies that are proactive, responsive, and indirect. This paper discusses the actions used to develop an accessible environment and the challenges encountered. The purpose is to disseminate the findings and promote discussion around the challenge of universally designing an accessible post-secondary environment.

BACKGROUND

In 1997 the University of Wisconsin-Milwaukee (UWM) began Project IMPACT (Integrated Multi-Perspective Access to Campus Technology). The University of Wisconsin-Milwaukee is a mid-sized, urban university with approximately 23,000 undergraduate and graduate students. The initial proposal included fifteen strategies for increasing access to assistive technology and accessibility of educational technology (1). In its third year, an integral part of this project is to disseminate discoveries and experiences. The Project IMPACT team believes that others can benefit from studying what we have encountered.

APPROACH

Initially, Project IMPACT's approach focused on accommodation in order to create accessibility. We have since determined that to be shortsighted. Accommodation and accessibility are related, but are two distinct approaches (2). Accommodation is still viewed as a necessity for individuals today, whereas accessibility, by following universal design principles, addresses future needs. Thus, along with environmental factor changes, including increased interest in universal design, recent legal rulings, and attention toward the future, Project IMPACT has shifted focus toward accessibility and universal design.

During the first two years of Project IMPACT, the team has implemented strategies including campus visibility, audits of campus accessibility, and direct assistive technology services for students with disabilities. Among new strategies has been the discovery and articulation of the A3 model (2). This model has been an effective tool in leading the team and educating others about the benefits of accessibility.

RESULTS - IMPACT ACTIONS AND CHALLENGES

The following is a list of IMPACT Actions that we believe contribute to developing an accessible post-secondary teaching environment.

1. <u>Link academic, administrative, and student support services</u>. The Project IMPACT team members represent Occupational Therapy, Exceptional Education, the Student Accessibility Center (SAC), the UWM Golda Meir Library, and Information and Media Technologies

(I&MT). Team members play different roles within their departments, including faculty, directors, chairpersons, direct service providers, graduate assistants, and managers.

2. Bring together a multi-disciplinary, core group to regularly discuss campus accessibility. The Project IMPACT team, representing education, engineering, assistive technology, educational technology, occupational therapy, rehabilitation counseling, and students, meets monthly.
3. Influence underlying campus documents such as strategic plans. Project IMPACT was instrumental in the inclusion of a tactic, "Ensure technology access to all faculty/staff/students with disabilities," in UWM's Learning Through Technology Action Plan.
4. Promote accessibility awareness on and off campus. We hosted 'Project IMPACT Day' as a day of campus activities to talk about IMPACT, tour facilities, and ask questions. Team members participate in recruitment and numerous conferences to disseminate information.
5. Participate in or consult for campus planning committees. Project IMPACT team members are actively involved in many committees related to campus planning and design, including the ADA Advisory Committee, classroom remodeling projects, the UWM on-line campus, and the campus map project. Participation has led to further committee invites.
6. Develop guidelines for information accessibility including forms, websites, and distance education. Recognizing that campuses are extending beyond the traditional classroom, Project IMPACT is actively involved in the development of distance education systems.
7. Develop and disseminate resources. Project IMPACT has developed one 'Mini Guidebook' titled "Information Accessibility: Ensuring Equal Access to Educational Opportunities for Students with Disabilities" for faculty, staff, and administrators.
8. Ensure policies and processes are in place for funding assistive technology and campus improvements related to accessibility. UWM has a campus policy for funding accommodations. Project IMPACT developed additional materials for assistive technology funding and is investigating potential use of student technology fees for accessibility.
9. Offer courses in assistive technology. Occupational Therapy and Exceptional Education, in conjunction with Project IMPACT, offer a variety of courses for majors and non-majors. The goal is to increase the assistive technology knowledge and awareness of professionals and peers. Most courses include accessibility as a content area.
10. Integrate accessibility strategies into campus training. Project IMPACT is in the process of working with various campus units to integrate accessibility and universal design information into instructional courses, such as beginning web design and I&MT student worker training.
11. Provide targeted feedback to campus units regarding accessibility of facilities, and services using multi-disciplinary audit teams. Occupational therapy students have performed 60 accessibility audits of over 40 different targets on or related to the UWM campus. IMPACT team members consulted in developing measurement instruments. The findings were then disseminated to the appropriate campus units. Project IMPACT is continuing to consult.
12. Implement a referral process for individual assistive technology and accommodation. Project IMPACT has developed a referral process and a team to provide screening and consultation to students with disabilities to meet present needs and incorporate accessibility in redesign.
13. Provide annual feedback to campus regarding efforts and achievements of accommodation and accessibility. We developed a 'Campus Report Card' that examines performance and effort in key aspects of campus accessibility. The grading system is based on an 'A' representing outstanding performance and use of universal design. A 'C' represents average or minimal performance and minimal fulfillment of legal requirements.

Project IMPACT has also encountered many challenges, both anticipated and unforeseen.

1. Focusing limited resources. The numbers of opportunities to infuse concepts for accessible design are plentiful. Thus, limited resources must be focused and efficient. Opportunities are easily missed, which is disconcerting.
2. Demonstrating exemplary accessibility. The team strives to be a model of accessibility in its operations. In some instances it is discovered that achieving accessibility is more difficult than initially thought. These experiences give insight into what other areas of campus are facing.
3. Limited internal and external assistive technology resources and changing computer use. The needs for assistive technology services were seriously underestimated in the initial proposal. The capacity of the grant allowed for short-term interventions and many students have more extensive needs. In recent years, we have seen computer competency become essential.
4. Synthesizing replicable model. While UWM is similar to many university campuses, it also has many unique features and people. The team is challenged to synthesize its findings into a generic model that other universities can replicate.

DISCUSSION

One year remains in current Project IMPACT grant funding. We will continue to implement strategies and report outcomes. We are in the process of moving this self-analysis into a set of recommendations for other campuses interested in implementing these systems.

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WHEELCHAIRNET: A VIRTUAL COMMUNITY FOCUSED ON WHEELED MOBILITY

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ABSTRACT

Virtual communities, a social form native to the Internet, are based on shared interests [1], and have already developed around childcare, investment, travel and older adult issues. A virtual community focused on wheeled mobility called WheelchairNet (http://www.wheelchairnet.org/) is in Phase I development. Previously the communication paths and information exchange within wheeled mobility circles were two-way, i.e., between researcher and manufacturer, client and clinician, supplier and manufacturer, etc. This community creates the potential for multidirectional communication among persons with differing perspectives and interests in wheeled mobility. This study describes the phases of development of a virtual community designed to create an arena where people could form relationships, re-think product design, and find solutions to problems that have slowed progress in mobility device reimbursement and innovation. WheelchairNet's development is being tracked with form questionnaires and web statistic software. This summary of early development experiences may guide others with similar goals.

BACKGROUND

Consumers are people who want the information about products that best meet their needs. The WWW is accelerating the growth of consumerism. Savvy entrepreneurs are using the WWW to reach directly to buyers and create demand for their niche products. Others reach beyond standard product marketing and use the WWW to learn more about consumer tastes, preferences and related interests to strengthen and increase customer loyalty [2]. Consumerism, already a factor in other healthcare sectors, is beginning to influence rehabilitation. In the past it has been difficult to become an informed consumer of wheelchairs. Information exchange was "top down." Consumers were primarily clinicians who recommended or prescribed mobility devices to less informed clients. Today, persons who use wheelchairs seek greater involvement in wheelchair selection and want information about model features, performance and reliability [3]. As never before, wheeled mobility device manufacturers have the ability to communicate with geographically diverse populations of both consumers and clinicians who want to communicate about products and propose improvements. This exchange can inform the marketing decisions of manufacturers and give valuable information about educational needs, product delivery and systems change. Likewise researchers can survey people who use wheeled mobility devices to learn more about the issues that affect daily life, safety, product use, and performance standards.

Existing virtual communities focus on topics or lifestyles for which it is difficult to find a real community. Within the community of persons who care about wheeled mobility issues like limited market size, sparse resources, time zone differences, low population density, and physical accessibility make it difficult to access peer support, user satisfaction, continuing education, and networking. A virtual community could create tremendous value for this group. We seek to determine if it can be created via Internet-based technologies. Though experts will say that knowledge can be easily separated from its product, program, practice, policy or public information vehicle, the dissemination vehicle selected may enhance or detract from the content it carries [4]. It is not known if the individuals who populate the actual community of interest in wheeled mobility --consumers, clinicians, manufacturers, suppliers, researchers, and funders--will use WheelchairNet to become citizens of a virtual community.

OBJECTIVE

Create a WWW-based resource to provide comprehensive, accurate, and timely information to a virtual community focused on wheeled mobility in a manner that will allow interaction, relationship development and a structure for contributed information. Design team goals were:

- Provide access to selected sources of information related to wheeled mobility.
- Provide access to best practice and current research to further excellence in wheeled mobility products and services.
- Support discussions, conversations, questions and answers (Q&A) using technology that allows community members to generate new topics.
- Establish a website that is responsive to suggestions, can be searched or navigated easily, and offers maximal web site accessibility for those with print handicaps.
- Open-ended governance that leaves the community free to decide on future direction, policy and leadership.
- Use of resources that respect persons with disabilities, honor intellectual property, and utilize World Wide Web Consortium and Web Accessibility Initiative quality standards [5].

METHOD

The WheelchairNet development team was comprised of a task leader with Internet and distance learning experience, an occupational therapist with both clinical and web development experience, a graphic designer experienced with web applications, and a health network and information systems expert. A plan for community layout and content was developed which captured content within the following categories: Products and Services, Community Living, Wheelchair University, Discussions and Listserves, and Town Hall. The team met bi-monthly to coordinate efforts, review progress, and modify strategies. The first task (months 1-6) was to consolidate disparate wheelchair resources to create a *portal* site where community participants could easily locate existing resources. Consistent page layout, a site map, a list of recent additions, "mailto" links to provide feedback opportunities and a search engine were implemented to increase the ability of users to find desired resources within the site. Gradually, as capacity and interest developed (months 7-12), lectures in Portable Document Format (PDF) with content of interest to consumers, clinicians, students and researchers were added to the site increasing its value as an *authority* site.

Several methods are being used to track the development of this community and to determine if it is progressing in the [2] normal sequence for a virtual community. An exit survey asks site visitors to rate satisfaction and give feedback on their site experience. Threaded discussions, powered by WebCrossing software, have been monitored since June 1999 when the site became open to the public. FunnelWeb, software that uses the webserver log to analyze site data on 10 dimensions is compiling graphic reports and showing site trends. ListStar, listserve management software, supports discussions on aspects of manual and power wheelchair technology such as those posted following the Stakeholder Forum [6]. Phase I is nearly complete with current efforts focused on building traffic by supplying site data to search and portal sites and publicizing its availability via consumer newsletters and professional networks. Phase II will concentrate traffic and Phase III will lock in traffic as a fully mature community thrives with active community participation [2].

RESULTS

Traffic has tripled for each month since site data tracking began (9/99 to 12/99). Areas of greatest traffic over a 3 month period (measured in quantity of information delivered) are: the index of mobility devices (3.5MB), the overview of all mobility devices and services (11.7MB), the site map (7.5MB), Wheelchair University (7.3) and the WheelchairNet Virtual Community overview for first time users (6MB). Initial visitor feedback indicates that many individuals are unaware of the purpose or value of a virtual community. Increased efforts are needed to educate the public (utilizing print and non-Internet media) about the availability of this resource. Feedback is essential for site improvement and for developing a community that is responsive to community member needs. Site visitors need structured opportunities to provide useful feedback to site developers. Interest in and utilization of threaded discussion is lagging behind expectations.

DISCUSSION

At the end of one year, WheelchairNet has met expected growth patterns. Remaining challenges include: developing communication among community participants, communicating the availability and purpose of a virtual community, building a sense of ownership, and overcoming the social and political boundaries that previously limited communication within this diverse community of interest. Although increased emphasis will be placed on the development of discussion forums, we will continue to explore other options to facilitate cross community communications.

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Interactive Multimedia Training for Assistive Technology Using Computer-Based Device Simulations and 3D Environments

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ABSTRACT

This project is designing, developing, and evaluating an interactive multimedia program to provide essential information and training on a wide range of assistive technology (AT) devices and systems for persons with disabilities, their families and advocates, and professionals who provide AT services. This training program incorporates a variety of instructional strategies and technologies including user-controlled, computer-based simulations of assistive devices and 3D rendered objects that can be viewed and manipulated by the user. The program allows the user to obtain information and training on: 1) the features and technical characteristics of a selection of assistive devices; 2) basic principles of operation of these devices; 3) technical requirements and compatibility information; and, 4) potential applications and typical uses of these devices.

BACKGROUND

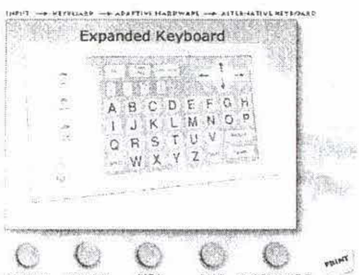
The National Council on Disability Study on the Financing of Assistive Devices and Services for Individuals with Disabilities (1993) pointed out that in spite of the positive impact that AT has had on the lives of many individuals with disabilities, it is clear that awareness, understanding and access to AT are still too often the result of where a person lives, their economic class and racial heritage. It has also been found that there is a lack of expertise in AT among persons with disabilities, family members, professional service providers and advocates (1). Although the situation is improving greatly, there is a scarcity of qualified AT service providers (2). Service providers are not easy to locate and, for those few who are available, there are great demands on their time (3). The Alliance for Technology Access (ATA) provides public education, awareness programs and a variety of AT related services at numerous centers throughout the U.S. In 1996 these centers provided direct services to 78,000 persons and indirect services to 235,000. In spite of these large numbers, the ATA estimates that fewer than 5% of people with disabilities in the United States have accessed their services in the last 10 years. A U.S. Congress Office of Technology Assessment Report in 1988 indicated that technology can indeed have a powerful impact on consumer outcomes if personnel have the training and skills to use the technology, an education that provides vision and understanding of developing technology, support for experimentation and innovation, and time for learning and practice (4). A number of other reports provide additional evidence for the need for expanded and improved AT training and information (5 -10). The interactive, multimedia program described in this paper is designed to provide a low-cost, easily disseminated, consistent, convenient and effective alternative for the many individuals who need essential information and training on the operation and uses of AT devices but do not have access to the necessary expertise or equipment.

METHOD

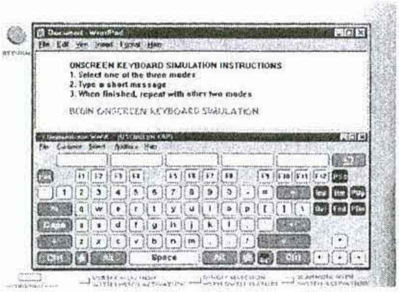
The program uses a metaphor of a community-based Assistive Technology (AT) Center. For purposes of providing a realistic experience, the entire environment, including AT devices, is rendered in three dimensions using 3D Studio Max (Kinetix). Within the AT Center are four rooms, each dedicated to a specific area of AT: an Adaptive Computer Technology Room, a Communications Technology Room, an Adapted Environments Room, and a Seating, Positioning and Mobility Room. Within each room the user is presented with a selection of 3D objects depicting the assistive devices. Interactive multimedia provides an effective means to learn about these AT devices and systems. The program uses a unique set of presentation and interaction technologies which enhance the learning experience through: interactive user control of the program content and sequence of presentation; viewing photographic images and 3D objects; viewing 3D animations of device configuration and functioning; user manipulation and 3D viewing of modeled objects using QuickTimeVR technology (Apple Computer); digital video presentation of uses of devices; user-controlled, operational simulations of a selection of assistive devices; and an embedded competency assessment. Multimedia authoring and programming of the device simulations was accomplished with Authorware Attain 5.1 (Macromedia). In the prototype only the Adaptive Computer Technology Room and associated AT have been completed. In this room, 25 broad categories of alternative input and output devices and software are presented. Competencies were identified for each of the categories of devices and incorporated into the instructional design of the program.

DESCRIPTION OF PROGRAM AND EVALUATION RESULTS

The figure on the left illustrates the Adaptive Computer Technology Room. On the left side of the room is a standard computer workstation. In the center is a shelf containing a variety of adaptive computer software. On the right is a shelf containing a representative variety of adaptive computer hardware. The user chooses one of these three components and then can choose to examine any of the objects at the computer workstation or on one of the shelves. As the cursor moves over the objects, each object is highlighted and the generic name for the object appears, for example, Expanded Keyboard, Dynamic Braille Display, Speech Recognition software, or On-Screen Keyboard.



For an example, if the user chooses the Expanded Keyboard object, the screen shown on the left appears. The image of the example keyboard (Intellikeys) is a geometrically and technically accurate 3D QuickTimeVR object which can be manipulated and viewed from any perspective. Along the bottom of the screen are four action buttons, a return button and a "Print" button to obtain a printout of essential information in PDF (Adobe). The four action buttons allow the user to select among: *Category Features*; *Products and Sources*; *Uses and Examples* which include images and video of typical uses of these devices; or a *Try it Out* section which presents the opportunity to interact with a simulated Expanded Keyboard with three programmed overlays. This interactive screen design is a common feature for each device in the Adaptive Computer Technology Room.



The figure at the left shows the screen that appears when the user selects the *Try it Out* button for the On-Screen Keyboard. The user operates the On-Screen Keyboard with the mouse and text is entered on a simulated word processor. The user may experiment with direct selection with switch activation, direct selection with the dwell feature, or row-column scanning activated with the mouse button.

The instructional value and usability of the prototype program has been evaluated by 62 AT professionals and consumers at the Closing the Gap Conference in October 1999 and at a number of other sites. Results of the evaluation indicate that there is a great need for the program; its value, potential effectiveness and ease of use were rated very high; and all multimedia components were found to be highly effective.

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INVESTIGATING INDUSTRY ATTITUDES TO UNIVERSAL DESIGN

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ABSTRACT

The general population in most countries is getting older. With increasing age comes increasing variability in physical capability and hence a greater requirement for products and services to be designed for a broader user base. However, the products to meet this market sector are not being produced to match the rate of market growth. Work-places are not generally being adequately adapted to support an increasingly elderly work-force. In response to this, the United Kingdom government has launched a series of research initiatives to encourage the uptake of Universal Design practices by industry. This paper describes the aims and goals of the I~Design project, the largest, multi-center, multi-disciplinary team funded under the latest round of these initiatives. It also discusses the findings of a workshop held to examine the attitudes of companies to the implementation of Universal Design practices.

BACKGROUND

The aging population is growing inexorably. By 2020, almost half the adult population in the UK will be over 50, with the over 80's being the most rapidly growing sector (1). With age comes an increasing divergence of physical capability (2). It will become increasingly important for industry to ensure that employees' working lives are not curtailed simply because of an inaccessible work-place. Avoidable premature medical retirement costs many large companies in excess of $200,000,000 per year (3), but not many companies are aware of the extent of this cost. In conjunction with this economic incentive to provide an accessible work-place, there is often a legal requirement to ensure that there is no discrimination on the grounds of physical capability. In the UK this is embodied in the 1996 Disability Discrimination Act, which is similar to the 1990 Americans with Disabilities Act.

New technology and products being developed by industry have the potential to improve quality of life and make working easier. However unless the technology is made available to everyone, then it also has the opportunity to alienate, so need to be as inclusive as possible. Many products continue to be designed to appeal to the younger generation and the lucrative, and growing, older market sector is being ignored. Consequently, large sections of the population are being excluded by industry attitudes. For example, of the FTSE 100 companies (the 100 largest companies traded on the London Stock Exchange) only 37% aim to produce products for the over-50's; 31% take end-user age into consideration when designing a new product or service; 29% agreed that aging will affect how they run as companies; and only 18% employ significant numbers of over-50's.

THE I~DESIGN TEAM

The I~Design project was formulated to address a number of the very basic issues affecting the uptake of Universal Design by industry. The I~Design team was conceived to be multi-center and multi-disciplinary and consists of members from: the University of Cambridge - Engineering Design Centre, Department of Psychiatry, Department of History and Social Population Structure, and the Cambridge Interdisciplinary Research Centre on Ageing (CIRCA); the Royal College of Art - Helen

Hamlyn Research Centre; The London Institute - Design for Ability, Central St Martin's College of Art and Design; and The Design Council. Industrial collaborators have been selected to represent a wide range of product developers, design consultancies and service suppliers. These include: The Post Office; the Chartered Society of Designers; and IDEO. User groups are represented by the Papworth Trust, a local residential disabled community, and the University of the 3rd Age.

RESEARCH OBJECTIVE

This research seeks to promote Universal Design by providing industrial decision makers with mechanisms to: assess the market size for new products, based on the whole population as opposed to the young and able-bodied (4); offer designers the guidance required to design for these markets; and understand the significance of age and capability related factors.

Central to this is examining the prevailing industry attitudes and identifying barriers to the uptake of Universal Design. It is also necessary to understand the requirements of the end users of products and services, and of the users of design information, i.e. designers, marketers and other decision makers in industry. This needs to be complemented by finding methods for selecting the most appropriate and effective design approaches. Once found, accessible formats for presenting the information to product development managers and designers need to be identified.

PREVAILING INDUSTRY ATTITUDES

The I~Design project was officially launched in October 1999 with a workshop in the Design Council's Design for Business Week. The aim of the workshop was to assess the level of industry awareness of the needs of the disabled and elderly communities and their openness to Universal Design. There were over 150 participants with representatives from a wide range of companies, including: British Telecom, Virgin Atlantic Airways, Omron Corporation, NatWest Bank and Tesco.

The initial stance of most of the industrial participants was that they were willing to implement Universal Design providing that it was either easy to do, or that a consultancy would do it for them, and providing that it did not increase the cost of the product or service. There did not appear to be widespread acceptance of the need for Universal Design training programs for designers or an appreciation of the potential increased market of more accessible products. The concept of 'undue burden' appeared to be anything that would cost more than the able-bodied version.

Stereotyping was also a very common problem. The misconception that designing for universal accessibility was a code-word for designing for the elderly and disabled only, and that this represented designing for the institutionalized. There was little understanding of aging as a gradual process that creeps up on everyone. One transport company had claimed to have made most of their buses more accessible by including spaces for wheelchairs on the lower deck of their double-decker buses. This was perpetuating the image of someone who is physically impaired being a wheelchair user. A walking-stick user, however, commented that this measure actually made the buses less accessible to her and others like her, who outnumber the wheelchair users, because there were fewer seats downstairs, making it necessary for her to climb to the narrow, twisting stairs to the upper deck.

However, encouragingly, there were also success stories to report. Tesco have redesigned their shopping trolleys to be shallower, and more maneuverable. OXO have developed the highly acclaimed GoodGrips range of kitchen accessories. The success of these products shows that there is a demand for more accessible items, but industry is being slow to respond. The common thread behind these is that the drive has been *top down*, from the senior management, rather than from the *bottom up*, driven by designer knowledge and training. This suggests that the best way to encourage the uptake of Universal Design may be to persuade senior management of the need for it.

However, awareness of the need to design for increased accessibility is not necessarily a guarantee that the goal will be achieved. In Rehabilitation Robotics, a field dedicated to design for the disabled, products have often failed because of lack of usability and accessibility (5). It is essential that designers are adequately equipped to implement Universal Design. In the second half of the I~Design workshop a number of design consultancies ran break-out sessions on designing products for the physically impaired. Those that were successful used empathetic, user-centered approaches, such as design by story-telling and body-storming. Less successful were the groups who tried to design without any attempt at empathy with the end users.

Other key results from the workshop included the importance of removing stigma from products designed to be more accessible. This is where both Tesco and OXO appear to have had the most success. By treating their designs as being simply more accessible mainstream products, rather than specifically developed for individual user populations, they have developed products that are genuinely more inclusive.

FUTURE WORK

It is important that the dialogue with industry is maintained and developed. Different design strategies may also suit different industry sectors. Further workshops will be organized specifically to identify methods for the successful implementation of Universal Design. It is envisaged that central to this will be the replacement of the *disabled and elderly* stereotypes with a view of users as coming from a broad spectrum of physical capabilities, irrespective of age and medical condition, and the development of tools (4) to make the implementation of Universal Design more straightforward.

The aging population is also a global issue and so needs a global perspective. Solutions that suit particular ethnic groups may not necessarily suit others. Consequently, it is essential to build an international dialogue. Future workshops are being planned in the United States and Europe and will be open to all interested parties.

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"*ASSISTIVE TECHNOLOGY SOLUTIONS:*" A NEW PARADIGM FOR THE DISSEMINATION OF ASSISTIVE TECHNOLOGIES

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ABSTRACT

The United Nations estimates more than 10% of the world's population is disabled. Assistive technology enables people with disabilities to lead more independent lives and increases their quality of life. Unfortunately, availability of assistive technology is limited for a number of reasons. First conceived in 1988, this project, called "*ASSISTIVE TECHNOLOGY SOLUTIONS*", is designed to establish a unique and innovative assistive technology transfer mechanism to make new or unique products and technologies available to people with disabilities throughout the world, and to do so without commercialization of the products. The project involves acquisition and dissemination, through the Internet, of engineering information necessary to duplicate and fabricate assistive technology devices. Armed with sufficient engineering information almost any kind of assistive technology device can be fabricated with appropriate local resources thus increasing the availability of assistive technology devices and fostering local enterprise in providing these devices.

BACKGROUND

Assistive technology has been shown to be effective in increasing the independence and the quality of life of people with disabilities. New devices, technologies and techniques of using existing technologies are continually being developed through assistive technology service delivery providers and research and development projects. People with disabilities and their families are also an important source of ideas and innovations in assistive technology. Such new devices and technologies address most of the problems faced by people with disabilities and in some way facilitate specific life functions and enhance their quality of life. Because these devices are often "custom-made," they are usually very effective. Often, those for whom devices are fabricated or customized are, themselves, instrumental in the design process, thereby ensuring the utility and acceptability of such devices. While there is a great deal of activity aimed at expanding the availability of assistive technology to people with disabilities, there is currently a shortage of rehabilitation engineers and sources of rehabilitation engineering that will continue over the short term.

Many of these devices are made because commercially-available products do not exist to meet the same needs. However, most such devices are not available to a large number of people who can benefit from them; rather, they are used by a limited number of people for whom the products were initially intended. There are at least two reasons for this. The first is that most of these products never become commercialized. Commercialization depends, in part, on the economy of scales, that is, whether a company can sell enough of the product to warrant setting up tooling and a manufacturing line necessary to produce it.

The second reason that such devices do not become more widely available is that the engineering information necessary to produce them does not become accessible. Although most of these products are never developed commercially, the basic and applied research, as well as the development or engineering of the product, have been completed. This means that the "non-recurring engineering costs" have already been expended. If the engineering information is available, then, in most cases, such products can be fabricated locally, using traditional mechanical, electrical and electronic techniques on a "one-of-a- kind" basis.

Developers of products often do not make available the engineering information that might enable others to duplicate or modify devices. In some cases, developers might hope that the product can be commercialized, thereby leading to larger profits. Therefore, these developers maintain their proprietary rights and do not make the relevant information available. The other reason is lack of an appropriate channel by which to make such information available. Many products are developed in the course of providing assistive technology services. However, these service providers rarely have the time or means by which to share these developments and devices with others.

PROJECT METHODS

Basic Premise of Project The project is designed to establish an assistive technology transfer mechanism to make new or unique products and technologies available to people with disabilities, and to do so without commercialization of the products. The project involves acquisition and dissemination of engineering information necessary to duplicate and fabricate assistive technology devices. The engineering information, in the form of plans, are sold. Originators or developers of devices who share their engineering plans are compensated by royalties from the sale of these plans.

In most communities there are available resources, although they are not usually associated with assistive technology, available to fabricate products on a "one-of-a-kind" basis. Volunteerism and a "do-it-yourself" attitude are prevalent in the assistive technology field. Often, fabrication resources can be obtained through family members and volunteers. If the engineering information about the products is available to these people, products can often be easily fabricated.

The project expands the availability of useful assistive technology to people with disabilities who can benefit most from the products. Some of the benefits of this approach include:

- ✓ Use of local resources for fabrication
- ✓ Use of volunteers or family members to provide labor in the fabrication of products (labor costs often account for up to three times the price of the parts of a product)
- ✓ Elimination of marketing and sales costs of commercialized products (marketing and sales costs often account for 1/2 the price of a product)
- ✓ Ability to "customize" design to meet the specific needs of the individual
- ✓ Incentives for inventors and developers to share their ideas when commercialization is not feasible
- ✓ Reduced likelihood of inefficient duplication ("re-inventing the wheel")
- ✓ More assistive technology options for individuals with disabilities and for clinicians working with them who are limited to the commercial market because they do not have access to engineering resources.

Although, as stated above, the labor costs of a product are often three times the cost of the parts, the parts' costs are minimized in a commercial product because of the economy of scale. Parts' costs for one-of-a-kind or custom devices can be expected to be somewhat higher than are those associated with commercial products. However, the incremental increase in parts' costs could be offset by savings in labor, marketing and/or sales costs.

There are advantages of utilizing local fabrication resources; however, product service and support can be problematical. Support for a commercial product can be expected from the supplier or manufacturer of the product. However, if the person who fabricated the device is not a commercial interest, but, for example, a volunteer or student, support for the product may be difficult to find later on. This project addresses these issues by selecting and designing products for easy maintainability and servicing.

RESULTS

The current project has been running for 1-1/2 years under an NIDRR Field Initiated Research grant at Cerebral Palsy Research Foundation in Wichita, Kansas. A website (www.atsolutions.org) has been established. To date, 25 plans have been created and are currently available by download from the site. Of these 25 plans, 10 are free. The source of most of these plans are projects and devices originally developed by the RERC and the rehab engineering service delivery program at CPRF. The plans are categorized into one of eighteen functional categories, i.e. architectural, computer, vocational management, home management, etc.

Website statistics are being tracked using "WebTracker" at www.fxweb.com. The site is currently receiving approximately 3 hits/day. Information about the website is currently being submitted to search engines which should significantly increase the number of hits experienced. At the present time, 74% of people visiting the website are one time visitors while 17% return to the site. Most visitors (31%) are using "net" domains. The next most prevalent domain is "edu" (14%). The table below illustrates the domains of the visitors to the website.

DOMAIN HIT PERCENTAGES	
.NET	31%
.COM	8%
.EDU	14%
.ORG	6%
.CA	6%
.AU	6%
OTHER	11%

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APPLICATIONS FOR A TECHNOLOGY TRANSFER MODEL

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ABSTRACT

This paper presents a summary model of the entire technology transfer process, and describes several applications for the model in practice. These applications include project planning, process orientation, resource allocation, and benchmarking. Applying this model can help plan, implement, track and assess the technology transfer process.

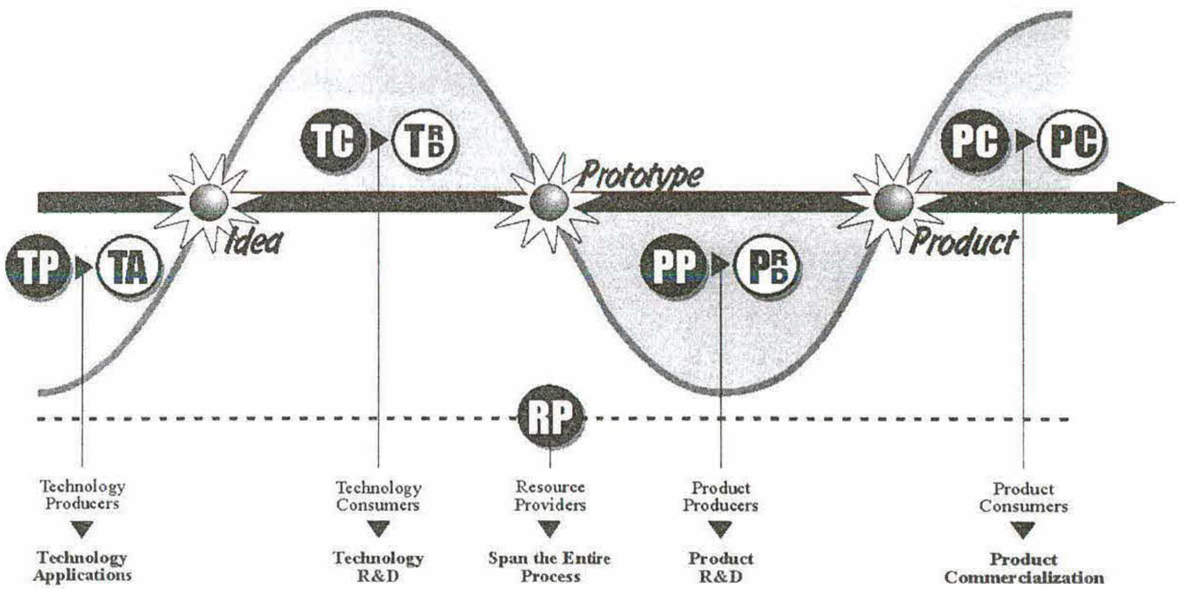
BACKGROUND

The concept of technology transfer is a popular one. In the absence of a solid foundation of literature, the term "technology transfer" has become synonymous with a range of activities. These activities actually describe elements of a larger process—technology transfer in the broader sense. Combining these definitions shows technology transfer to be a complex process involving a wide range of participants in multiple inter-dependent activities (1). By understanding the entire process, and placing activity within this context, participants properly apply technology transfer as a concept.

APPROACH

The RERC on Technology Transfer developed a comprehensive model of technology transfer (Figure 1) (2). It shows that technology transfer starts with an idea for a technology application and ends with a commercial product (3). The model's activities, events and stakeholders all contribute to one process.

Figure 1. A Model of the Technology Transfer Process ©University at Buffalo



The technology transfer process can be initiated from either end of the process: "supply push" from the technology side, or "demand pull" from the product side (See arrows in Figure 1). *Supply Push* means that the transfer process starts with an identified technology that is seeking an appropriate application (4). *Demand Pull* means that the transfer process starts with an identified unmet market need which is seeking an appropriate solution (5).

Figure 1 depicts the three points of intersection between the wave and the axis in the technology transfer process. These three points of intersection represent the three critical events in the technology transfer process: idea, prototype and product (6). The *Idea Event* is the point at which a specific idea is conceived—an idea that identifies a new discovery or existing technology and matches it to a new or novel application. The *Prototype Event* occurs when the idea for a technology application is developed into a functional prototype. The defining moment is when the prototype demonstrates that the technology concept functions as expected in reality; where the technology concept is first reduced to practice. The *Product Event* is when the prototype has been developed to the point where it is ready for production and distribution for the marketplace. At this point, the product's components, design and operation appear reliable and are reproducible in mass numbers.

In Figure 1, the sine wave and horizontal axis together form boundaries around four areas—two above the axis and two below it. These four areas represent discreet activities around the three critical events. *Technology Applications Activity* represents all of the individual thinking and all of the group communication that precedes the conception of a new idea. *Technology R&D Activity* encompasses the intellectual and physical activity involved in transforming an idea for a technology application to a prototype form. *Product R&D Activity* is all that is involved in transforming a prototype device into a product ready for commercial production. *Product Commercialization Activity* includes the manufacturing, distribution, sales and support for the product.

The technology transfer process has five stakeholder groups, two involved with production, two involved with consumption, and one resource provider group. Each group is a vital stakeholder in the technology transfer process (7). *Technology Producers* conduct the technology application activity and first generate the idea for matching a technology to a new application (e.g., inventors and researchers in academic or federal laboratories and companies). *Technology Consumers* include government agencies with a mission to apply technologies to serve national needs (e.g., defense, space exploration, veterans' health care), private sector manufacturers seeking to develop new products based on advanced technologies, or intellectual property brokers in the business of re-selling technology. *Product Producers* include manufacturers of products, distributors of products through domestic and international markets, and value-added retailers that offer the products for sale to consumers and provide services to support the products. *Product Consumers* include end-users and family members who acquire and use product, and professional service providers who prescribe or recommend products. *Resource Providers* include government and private entities that fund technology development and product acquisition, programs that analyze and change policies and systems, and technology transfer intermediaries such as the RERC on Technology Transfer.

RESULTS

Developing a comprehensive model of technology transfer has proven to be a useful exercise for better understanding the process itself. It has also shown itself to be a useful tool for multiple applications such as project planning, process orientation, resource allocation, and benchmarking.

The model acts as a template for project planning, to help ensure the necessary activities are considered, the appropriate stakeholders are included, and that a project schedule reflects the work ahead. For example, planning a technology transfer project that omits the Technology R&D activity, will artificially reduce the time required for the Technology Consumers to complete their necessary tasks.

The model also serves as a roadmap of sorts, to orient people currently engaged in the process, to establish the location of their current activity, and helps determine what needs to be done next and who needs to be involved in doing it. An inventor may be trying to interest a company in a prototype, but may be exaggerating the value of the Technology R&D activity in the overall process. The model shows the inventor how much additional investment is required on the part of a manufacturing partner (Product R&D),

before the Product critical even is even reached. This roadmap also reminds people engaged in the process that their final goal is Product Commercialization, rather than the singular critical events of Prototype or Product creation.

Resource allocation -- both time and money -- is a crucial element of technology transfer because the resources available are finite and typically less than those eventually required. If Technology Consumers are preoccupied with endless prototype revisions, they can miss their opportunity to pass the device on to a manufacturer that typically has a time window for new Product R&D activity. Resource Providers must be particularly aware of the resource allocation across the entire process, or they may expend all the available resources before the product's critical event is achieved. This is one reason why the Product R&D activity is called the "valley of death" in product development literature.

Project benchmarking is a summative evaluation technique whereby one compares actual performance to some standard. The model helps analyze data for benchmarking purposes by providing a structure in which to organize data collection, and then to apply the resulting analysis. Our program is benchmarking our role as a technology transfer intermediary, for each of the activity areas and in support of each of the stakeholder groups.

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THE DEMAND PULL PROJECT ON WHEELED MOBILITY

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ABSTRACT

Demand-pull technology transfer is a process that starts by identifying an industry's critical technological needs and then seeks technological solutions from parallel industries, the federal labs, research institutions and other technology developers. The Demand-pull Project on Wheeled Mobility identifies critical technological needs for the wheeled mobility industry (e.g. manual wheelchairs, power wheelchairs, scooters); develops problem statements representing those needs; solicited responses (technology proposals) from technology developers and then screens and offers promising technology proposals to manufacturers.

BACKGROUND

Starting in November 1998, the Rehabilitation Engineering Research Center on Technology Transfer (T^2RERC), partnered with the RERC on Wheeled Mobility to conduct the *Demand-pull Project on Wheeled Mobility* (1). The goal of this Project is to identify unmet needs in the wheeled mobility industry (manual and power wheelchairs, and scooters) and to facilitate the transfer of technology solutions from government laboratories, research institutions and other advanced technology developers to meet these needs (2).

Following a series of expert interviews, the Project focused on four technology areas: manual wheelchair propulsion; motors and drive-trains; materials and components; and power, power management and monitoring. Technology needs identified within these four areas represent important and unmet customer needs that also represent a significant business opportunity for manufacturers. Further, technology solutions required to address these needs are likely to be beyond current industry capabilities or resources.

Problem statements therefor represent *specific technological improvements desired by wheelchair manufacturers, and having consensus support from all other stakeholder groups.* Technological solutions to these problems will address high priority needs within the Wheeled Mobility industry.

METHOD

The T^2RERC demand-pull project utilizes a five-step process (3):

1. Select Industry Segment - The partner RERC has a key role in selecting the industry segment and identifying candidate technology needs where solutions to address these needs are likely to require advanced technology solutions. Selection of the industry segment and general technology needs serves to focus subsequent project activities.

2. Identify Technology Needs - Selection of specific technology needs relies upon the triangulation of information gathered from product end-users, technical and clinical experts and manufacturers. Panels are utilized to obtain end-user information while clinical experts and manufacturer interviews identify further customer needs, product state-of-the-practice, limitations in the underlying technology, and business opportunities. The T^2RERC works to ensure that the confidential information and intellectual property of manufacturers and researchers is protected.

An industry profile and "white papers" for each specific technology need are developed which expand upon information gained through the interviews and panels. White papers include information on unmet customer needs; market information; business opportunities; and technology state-of-the-practice for products now in the market. The industry profile includes: manufacturers and products, markets and market size, distribution channels and reimbursement issues, trade shows, conferences and other factors.

3. Validate Technology Needs – A stakeholder forum is the principle means by which technology needs are validated. Forum participants include (but are not limited to): product customers (e.g. end-users, clinicians, service technicians, ...); referral and reimbursement experts; clinical researchers; product producers (manufacturers); innovators of new technology (e.g. laboratory, university and industry scientists); and representatives from various governmental agencies. Prior to the forum, each participant receives the industry profile and white papers. Forum outcomes include the following:

- Identify significant customer needs not addressed by currently available products.
- Establish that unmet customer needs represent a significant business opportunity.
- Establish that significant technical innovation is required to meet these customer needs.
- Establish that the needed technical innovation is probably beyond the current means or capabilities of manufacturers within the industry segment.
- Establish design and performance targets for the needed technical innovation.
- Identify barriers that might prevent the development or transfer of this technical innovation.

4. Locate Technology Solutions - Problem statements are written based upon Stakeholder Forum outcomes and all prior work outlining the unmet needs; business opportunities; technology state-of-the-practice for products currently in the market; specifications and parameters for the 'technology solution;' and barriers/impediments that must be overcome to achieve this ideal technology. Problem statements are disseminated through web-sites, newsletters, journal articles; and email and phone contacts to technology producers and target federal laboratory scientists, advanced technology manufacturers and university researchers.

Responding to these problem statements, technology developers can submit non-proprietary technology proposals in hard-copy or through a web-site. Technology solution proposals are reviewed by technical and industry experts to confirm that the proposal addresses the stated need and is technically feasible. For promising technology proposals, additional proprietary information may be requested from the technology developer. In such cases, mechanisms to protect intellectual property are worked out between the technology developer and the T^2-RERC. All proposed technology solutions are available to the partner RERC.

5. Transfer Technology Solutions – Staff at the T^2RERC prepare a commercialization package that summarizes the customer needs being met; market opportunity; proposed technical solution, and the business plan to transfer this solution and market downstream products. A marketing plan is developed by which to contact and present this commercialization package to manufacturers. The transfer of technology is completed through mechanisms such as direct licensing of the technology to a manufacturer; or a cooperative research and development agreement (CRADA) between a federal laboratory and a manufacturer.

RESULTS

As of December 1999, the first three steps (Select Industry Segment, Identify Technology Needs, Validate Technology Needs) of the Demand-pull Project on Wheeled Mobility were fully complete and the fourth step (Locate Technology Solutions) was partially complete.

Following panels and expert interviews, white papers were developed in four technology areas: manual wheelchair propulsion; motors and drive-trains; materials and components; and power, management and monitoring. White papers, industry summary, and forum attendees can be reviewed at the RERC on Wheeled Mobility URL: http://www.wheelchairnet.org/wcu/wcu.html.

The Stakeholder Forum on Wheeled Mobility was held May 24th and 25th 1999 in Pittsburgh Pennsylvania, hosted by the RERC on Wheeled Mobility and managed by staff from the RERC on Technology Transfer. Six problem statements were subsequently developed: geared hubs; power monitors; chargers; tire materials; motors; and transmissions. Problem statements can be reviewed at the Research Triangle Institute URL: http://www.rti.org/technology/wheelchairs.

The "Proceedings for the Stakeholder Forum on Wheeled Mobility," were written and mailed to Forum participants and other stakeholders. These Proceedings include a summary of the industry profile; white papers; forum outcomes (data gathered from forum participants); problem statements; forum evaluations; and participant contact information. As of December 1999, the project had been written up in five major newsletters and journals. More than three-hundred federal laboratories and many additional technology developers had been contacted and provided with project background, URL sites and other related information.

The T^2RERC is required to identify and disseminate (e.g. training materials, seminars, publications) any "best practices" maximizing the efficiency and effectiveness of the demand-pull tech transfer process. A case study is underway that evaluates the carriers (intermediate outcomes such as: the industry profile, white papers, problem statements) and barriers (impediments) to the demand-pull technology transfer process. Barriers include such things as: the need to demonstrate explicit manufacturer interest to technology developers; the need to identify and directly contact specific federal lab researchers; the need to educate federal laboratory consortium representatives about the needed technology and the business opportunity it represents; planning and lead time to reduce logistical bottlenecks; and issues relating to the handling of proprietary information.

As of December 1999, we had received approximately ten technology proposals from federal lab scientists and other technology producers. Efforts to disseminate problem statements; and solicit and screen technology proposals will continue until such time that appropriate technology solutions are identified. Outcomes for the last two project steps (Locate Technology Solutions, Transfer Technology Solutions) and the project case study will be presented at the year 2000, RESNA Annual Conference.

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ESTABLISHING BEST PRACTICES FOR TECHNOLOGY TRANSFER – PRELIMINARY FINDINGS

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ABSTRACT

The Rehabilitation Engineering Research Center on Technology Transfer (RERC) of the State University of New York (SUNY) at Buffalo, in an ongoing effort to establish best practices in technology transfer, is conducting research to study the feasibility, performance and validity of two innovative approaches. This paper presents preliminary findings from our first year's experience, focusing on the *Performance Benchmarking* study in relation to the models. It also discusses the relation of the findings to the other research components of the program.

BACKGROUND

The RERC on technology transfer at SUNY, Buffalo is in its second year of implementing a research and development program seeking to improve quality of life for persons with disabilities. In an effort to develop best practices that transfer technology into the disability area, the program is evaluating two models - demand-pull and supply-push. The first model identifies and "pulls" state-of-the-art technology into the disability area, targeting technology consumers and product producers, based on systematic research of their needs. The second one identifies potential product supply, improves them through research on technical, market and end-user needs and "pushes" them into the marketplace. The research in progress seeks to establish the feasibility, performance and validity of the two models through two studies, ***Performance Benchmarking*** and ***Critical Factors.*** This paper presents our methods and preliminary findings from our first year's experience in relation to the performance benchmarking study.

METHODS: DATA SOURCES, INSTRUMENTS AND ANALYSES

Benchmarking performance addresses the *merit* of the models (1), focusing both on how our processes are performing, and what *efficiency* level they are reaching. We do this mainly by tracking personnel time on activities (indicating cost) and our outcomes (indicating effectiveness). Efficiency is model effectiveness per person-hour units spent.

For tracking personnel time on activities, our reference points are the protocols or the *action plans* that guide each subproject. Project members fill out weekly time sheets, and we generate person-hours by activity and per subproject. We prepare quarterly updates on summary charts of person-hours distribution, that give comparisons between activities and between quarters.

For tracking outcomes, our reference points are the "critical" or transition points significant to each model process. Examples from demand-pull would be industry profile, white papers, problem statements and technology solutions. For supply-push, they would be agent agreements, improved product designs, and commercialization packages. Our data consists of evaluative feedback from industry, researchers and end-users - our participating stakeholders. Their dual role evaluates our intermediary outcomes at the same time providing input to subsequent process steps. We collect this data through focus groups, surveys (mail-out and telephone), interviews and on-site observations of significant events such as the stakeholder forum.

Our analyses aggregate time and outcome data sequentially around the critical points for each model. We do this both quantitatively and graphically in a way that leads us to a preliminary view of model efficiency.

Developing best practices involves both *formative and summative evaluation* of the models (2), (3). Our outcome data from stakeholders is our guide to perform both. While our analyses for efficiency relate mainly to the *summative* or overall evaluation of the models, our *formative* or continuous evaluation results in improvement of our model processes and outcomes themselves. For details see our website at wings.buffalo.edu/ot/cat/t2rerc/programs.htm

RESULTS

Our findings from the first year (see Table 1) mainly relate to process efficacy based on time tracking. According to our findings (see columns 7 and 9), the pattern of time utilization by

Table 1: Overview of Time Spent on T2RERC Activities in Year 1

	Person-hours spent							Planned	
	Q1	Q2	Q3	Q4	Total spent	%		Person - hours	%
Project Support	***985.5***	756.8	673.3	1005.0	***3420.6***	***19.7%***		1760.0	10.0%
Demand-Pull [WhMob]	591.0	760.8	2139.9	134.5	3848.2	22.2%		1920.0	10.9%
Demand-Pull [Hearing]				222.0					
Supply-Push	855.5	1810.5	1281.0	951.2	4898.1	28.2%		6408.0	36.4%
Eval/Res	***519.3***	429.5	514.8	530.3	***1993.8***	***11.5%***		2596.0	14.8%
Tech assistance	57.0	72.6	66.3	194.0	389.8	2.2%		832.0	4.7%
Dissemination	197.5	337.3	641.7	909.7	2086.1	12.0%		2976.0	16.9%
Strategic Partnerships	98.8	140.3	188.0	279.5	706.5	4.1%		1096.0	6.2%
Total					***17343.0***	100.0%		**17588.0**	100.0%

different project activities very closely followed the time distribution we expected based on our relative priorities set for them. Very appropriately, *supply-push* and *demand-pull* activities, our two main efforts consumed major time portions. Next in order comes *project support,* which includes personnel training and logistical support. *Dissemination* and *evaluation/research* follow project support in this sequence. Indeed, the project has utilized the least of personnel time on building strategic partnerships and providing external technical assistance.

Two comments, however, are in order. First, project support consumed more personnel time than dissemination and evaluation activities, contrary to our prediction. We must point out that our start up logistics (equipment/workstation set-ups) inflated this initial time consumption, after which it steadily dropped. It went up again due to time spent on hiring and training of our graduate student work teams. Secondly, our demand-pull project started out with a very conservative time estimate (about 11 %), as compared to supply-push, and gradually increased its resource consumption over the year. This is because this year constituted a "pilot" experience for demand–pull, while our supply-push project had head-start knowledge from the previous project cycle.

Throughout the year, there was sharing and redistribution of personnel between the two model processes. Reading across columns 2-5 in Table 1, we can see demand–pull's time requirements rising gradually over the year, peaking dramatically in the third quarter, which was when its forum was held and significant outcomes were being reached. Its demand then declined as it weaned out into groundwork on its second year's activities on hearing technology. On the other hand, supply push had its peak action in the second quarter, gradually decreasing its demands and giving up personnel in favor of the other subprojects in need. In particular, *dissemination*'s demands steadily rose in keeping with the project's accumulating outcomes ready for dissemination, peaking at the very end. The steady pattern of *evaluation* activities, on the other hand, reflects the project's philosophy of continuous program evaluation and improvement.

Overall, therefore, the findings confirm the efficacy of project processes in terms of using resources to maximize our prioritized goal accomplishment. Analyses are in progress to integrate these with outcome data to complete a preliminary view of model efficiency. The findings were used, in addition to evaluating the models, as feedback for ongoing program process improvement (4).

DISCUSSION – WHERE DO WE GO FROM HERE?

Our current analyses are completing the effectiveness-efficiency profile of the individual models. Time distribution charts, similar to Table 1, permit comparisons *within* each model between critical activity blocks and so do our data on the corresponding outcomes. Overlaying the two graphs on the same time-axis of reference will lead us to a view of model effectiveness and efficiency.

The analyses in progress also include findings from the *Critical Factors* study, not described in this paper. They complement our quantitative findings from the benchmarking study, describing qualitatively (5); (6) how each model worked to achieve its level of effectiveness and efficiency. They identify the factors that impeded or facilitated the technology transfer process, and relate findings to *best practices*. We expect to start cumulative analyses and to develop case studies (7), (8) for dissemination from the second year on, describing the uniqueness of our experience.

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DISTANCE EDUCATION: TAKING IT TO THE NEXT LEVEL

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ABSTRACT

A new structure for delivering an online masters degree in Rehabilitation Counseling is being implemented across three rehabilitation regions to meet Comprehensive System of Personnel Development (CSPD) requirements. This article provides a description of how the web-based degree program has changed since the first cohort of students began coursework in1997. Evaluating the effectiveness of the instructional design and delivery has provided valuable insight on how to improve the teaching and learning strategies by accessing a variety of instructional technology formats. The *Applications of Rehabilitation Technology* course is used as an example of how the lessons learned are being integrated into the new cohort's degree program.

BACKGROUND

San Diego State University (SDSU) first offered a 30-month web-based masters degree in Rehabilitation Counseling in February 1997 to 34 practicing rehabilitation counselors from California. A second cohort of 24 counselors from California and Nevada began18 months later. As of November 1999, a multi-tiered approach to distance education was launched in order to meet the Comprehensive System of Personnel Development (CSPD) requirements. This federally funded initiative was enacted as a vehicle to increase the education level of rehabilitation counselors working for state agencies, as designated by the educational requirements of the Reauthorization of the Rehabilitation Act. A collaborative agreement was designed by the directors of the Rehabilitation Continuing Education Programs (RCEP) from Georgia State University (Region IV), the University of North Texas (Region VI), and SDSU (Region IX) to identify 50 students from each of the three regions. The challenge for providing appropriate, accessible, and interactive instruction for 150 students from coast to coast required a careful look at the progress and problems faced by students, instructors, and the instructional technology team involved in the first two cohorts.

Effective distance learning incorporates strategies for delivering content effectively, engaging students in active learning, and offering an approach that is "flexible, multiple-perspective, experiential, project-based, and holistic -- what is often referred to as student-centered" (Berge, 1998, p. 21). Distance education typically includes the use of e-mail, the World Wide Web, online resources, and a range of web-based formats that provide unique opportunities for instructors to increase interactions with and among students. Students discuss readings and assignments via small group or whole class listservs, post comments on discussion boards, and participate in real-time conversations in "chat rooms." Specially designed software enables students to submit assignments directly on the website, eliminating the need for attaching files or changing formats.

CHALLENGES

The advantages of distance education include convenience, flexibility, self-direction, and a less intimidating atmosphere than is sometimes found in a face-to-face classroom. However, critics suggest that there are drawbacks to this approach. Questions often asked of "virtual" professors include: Does instruction become more homogeneous? Are effective models of teaching and learning compromised? How much enthusiasm and participation can be generated online? Do students feel isolated? How are accessibility issues addressed? Instructors, students, as well as technical support staff, all have roles and responsibilities in maximizing learning opportunities as well as creating a sense of community in virtual environments, just as they do in physical classrooms. By addressing these issues with the first two cohorts, the faculty and staff are in the process of improving existing activities and creating new designs for content delivery in the tri-region cohort. Data collected through the use of online course evaluations , student focus groups, and individual interviews with students and instructors provided honest feedback and constructive suggestions. The newest cohort structure is designed with a multi-level approach, that is, with one master professor directing six regional facilitators who are each assigned 25 students. The students selected must meet both regional guidelines and university entrance criteria.

STRATEGIES

The *Applications of Rehabilitation Technology* course in the first cohort utilized approaches that caused some inconvenience. For example, students reported that downloading the home page took too long because of the number of pictures posted. They also disliked using the chat rooms as it was often difficult to coordinate meeting times. Although not unique to distance education classes, group work presented challenges for many of the students, especially for those who felt that they were doing more than their fair share. Most students commented on the length of the course, recommending that it be extended to 12 weeks (versus the original 8). These suggestions were incorporated in the redesign of the *Rehabilitation Technology* course for the second cohort.

The home page had anew look. The original photos, which had been used to illustrate case studies, were moved to a separate page. A "What's New" section greeted the students and reviewed the assignments and activities for the coming week. This reminder highlighted points made in the weekly introduction sent via the class listserv. This section also included links to the week's discussion board, activity, or related references. By lengthening the course to 12 weeks, the instructor engaged the students in more activities that involved applying theory to practice. The first cohort's activities were limited to weekly discussion boards on which they responded to questions based on the text, supplemental articles, videos, and other materials that had been mailed to each student. In the second cohort, the boards were redesigned with new functions. The first board was created for students to post a summary about an assistive technology device found in the media. Another discussion board shared information from the annual RESNA conference that was in progress during the class. Students asked questions about the conference and viewed digital photographs downloaded on a special site linked to the course homepage. The "Brainstorming Board" featured scenarios submitted by students. The class members offered assistive technology solutions based on their experiences, course materials, and related research. Some of the busiest discussion boards were those hosted by "virtual guest speakers" who covered topics according to their expertise, e.g., ADA accessibility, universal design, computer access options, and the use of effective counseling techniques in determining assistive technology needs. Each guest posted a weblecture and then discussed the topic with the students for the rest of the week. The chat rooms were deleted, group work was restructured to allow more flexibility, and all materials and websites were reviewed for maximum accessibility.

FINDINGS

Formal and informal course evaluations indicated that the students were very satisfied with the variety of activities incorporated in the class sessions and that they were sharing information about assistive technology with their colleagues. Nearly all of the students mentioned the usefulness of the resource links and were relieved that they could continue to access the website after the course ended. Comments included that they, as rehabilitation counselors, felt "more informed about assistive technology," "confident about doing their own research on A.T.," and "could communicate better with A.T. professionals and be a valuable member of the team." One student summed up his experience, noting that "it's up to all of us to stay informed on A.T."

CONCLUSION

Applying the lessons learned from the first two cohorts will be invaluable for designing the *Rehabilitation Technology* course for the tri-region program. Like anyone new to distance education, the rehabilitation counselors felt overwhelmed when presented with too many technical responsibilities. Not only were they learning assistive technology content, but at the same time were becoming familiar with new instructional formats. Students in both cohorts commented on an ironic realization discovered through their virtual learning experiences. They developed a clearer understanding of the challenges and discomfort that individuals with disabilities often face when deciding on assistive technology devices. They learned first hand that it takes time, support, and patience to integrate new technology, assistive or otherwise.

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COMPENSATING FOR COGNITIVE DEFICITS THROUGH ASSISTIVE TECHNOLOGY

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ABSTRACT

A project was proposed to the Developmental Disabilities Council to enhance, through assistive technology, the transitioning of people with developmental disabilities from the sheltered workshop environment into community integration.

The purpose of this project was to demonstrate assistance or enhancement of transition for people with cognitive deficits through the use of assistive technology and accommodation who would not otherwise be able to experience community integration. The target population was those people within the Employment Related Activity Program with cognitive deficits who would need accommodation in order to transition from the sheltered workshop setting into community integration. The goal was to assist 5 clients per year for three years.

In less than two years, 11 clients have been served through a total of 41 accommodations. These accommodations have helped the clients to perform more types of job tasks with greater productivity and accuracy, which also resulted in an increase in the clients' self-esteem and income.

BACKGROUND

Work Activity Centers strive to place clients with cognitive disabilities into competitive employment in the local community. Many of these clients are physically able to perform some or all of the required job tasks but are unable to handle the cognitive demands of the jobs.

OBJECTIVE

The object of this project was to integrate the Assistive Technology capabilities of the T.K. Martin Center for Technology with the needs of the clients of Life Help Industries to enhance work productivity by modifying the environmental issues related to specific job tasks to compensate for the cognitive deficits and capitalize on the physical capabilities of the individuals.

METHOD

A rehabilitation Engineer and a Co-op student were assigned to work with clients identified by the staff of a work activities center to evaluate the clients' abilities and limitations in performing selected job tasks within the workshop and in competitive employment situations. The productivity of the clients was determined prior to accommodations. The job tasks were then re-engineered and assistive technology devices were fabricated to help compensate for whatever limitations the clients had. Productivity of the clients was again evaluated.

The goal of the project was to evaluate 5 clients per year. Those with mild and severe cognitive impairments were targeted for inclusion in this project.

Some clients had already been identified for competitive employment positions prior to the start of this project. Accommodations were made to the identified job positions. Other clients were evaluated within the workshop. After the application of appropriate assistive technology, they became eligible for outside positions. These new outside positions were then evaluated for the need for assistive technology.

RESULTS

The initial goal for this project was to assist and evaluate 5 clients per year. After a year and a half, 11 clients have been directly assisted by a total of 41 assistive technology accommodations. The accommodations were cognitive, physical, or a combination of both. In addition, many other clients in the workshop have benefited by having access to the accommodations.

Accommodations have been made to a total of 22 tasks. These accommodations not only increased the efficiency and quality of the work of each person for whom the accommodation was made, but also allowed 1 to 7 additional clients (mean = 2.7)to perform the tasks.

As an example, a Christmas card folding jig allowed the workshop to prepare 8000 cards in two weeks. Last year, without the jig, the workshop needed 2 months to fold 5000 cards.

Only two of the accommodations cost over $100.00.. Twenty-six of the accommodations cost less than $20.00. This is only the cost of the supplies needed for the fabrication of the accommodations. It does not include the cost of engineering time to develop the design. Fabrication time for the accommodations ranged from 1 hour to 48 hours.

In addition to increasing the productivity of many tasks, the accommodations also allow more clients to perform the tasks and allowed most clients to perform tasks which they could not previously perform. The following chart shows the improvement in the time to complete four representative job tasks. Tasks A, B and D are packaging tasks, and task C is a stapling task.

DISCUSSION

The proper application of appropriate assistive technology has resulted in a decrease in the amount of time needed for clients of a work activities center to complete job tasks they were already capable of accomplishing. It also resulted in an increase in the number of tasks each client could perform, as well as an increase in the number of clients who could perform any tasks at all.

The expectations of the project were exceeded both in the number of clients served and in the increase of capabilities of the clients themselves. The increase of capabilities of the clients has also resulted in a higher self-esteem for the clients as well as an increase in income.

The accommodations not only increased productivity, but also have resulted in an increase in quality of the completed product or job outcome.

ACKNOWLEDGEMENTS

This Project was funded by the Mississippi Developmental Disabilities Council through a grant to Life Help Industries of Greenwood, Mississippi.

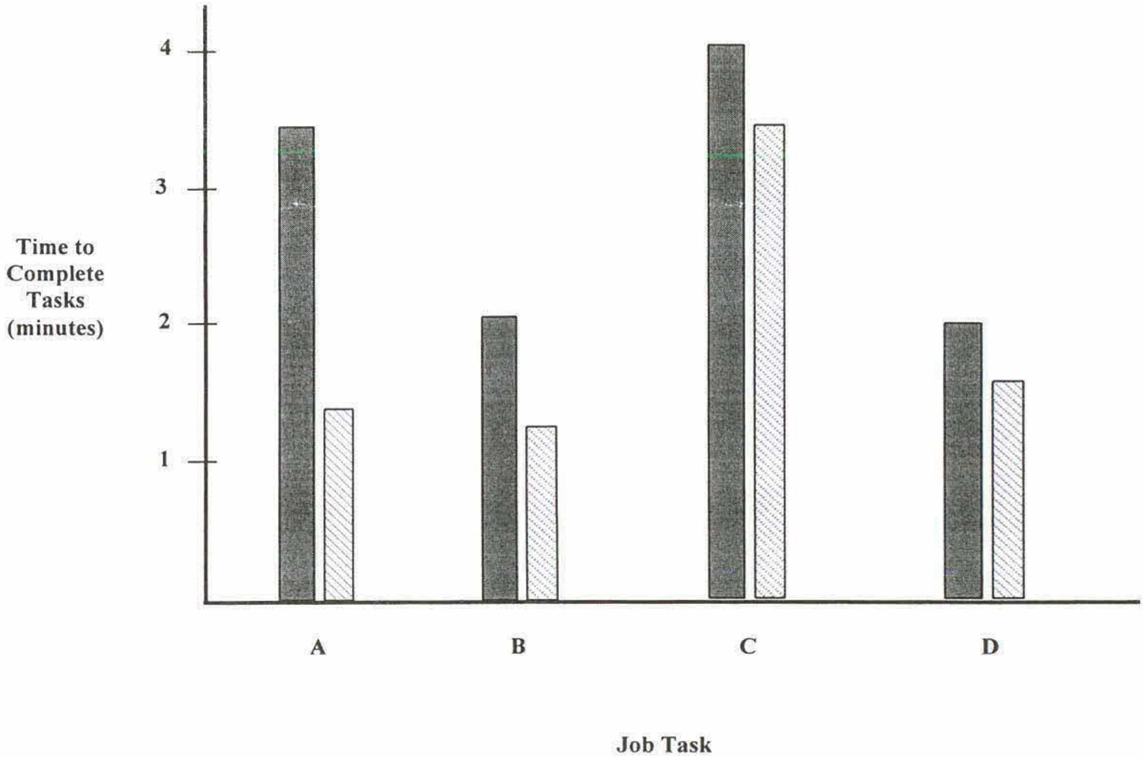

Chart 1. Reduction in Time to Complete Tasks

A. **Client PM - Stove Grate Packaging Task**
B. **Client CJ - Fish Jig Packaging Task**
C. **Client CJ - Fish Jig Stapling Task**
D. **Client WW - Fish Jig Packaging Task**

IN-SERVICE TESTING OF MATTRESSES USING THE QUINCE MATTRESS TESTER

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ABSTRACT

The QUINCE in-service mattress-tester is a portable, easy-to use, interactive device that quickly gives accurate information as to the condition of a mattress in a clinical setting. The device is validated against accelerated fatigue, pressure mapping of bottoming with healthy volunteers, and service life of 150 mattresses. The QUINCE SUPPORT SCORE provides an objective and valid basis for a mattress replacement programme.

INTRODUCTION

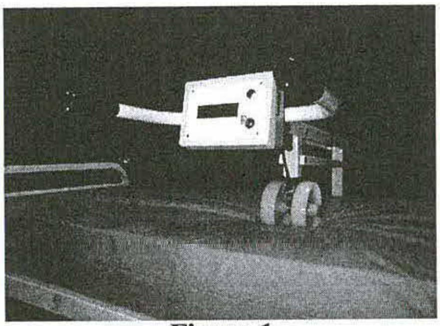


Figure 1

It is widely recognised that mattresses have a finite life-span (1). In particular hospital mattresses, typically made from polymer foam materials, are known to degrade over a period of years (2). Fatigue of a mattress in this way leads to a phenomenon known as 'bottoming' (3). This refers to the yielding of the mattress to such an extent that the occupant comes into close contact with the hard base of the bed: an important condition to avoid as it represents an aggravated risk factor for pressure ulcers (4). Most hospitals now appreciate the need for a mattress replacement programme, and cost analysis shows there are economic benefits in replacing dangerously fatigued mattresses (3). There have been calls for more objective evidence regarding the life span of hospital mattresses to assist with decision-making surrounding purchase and disposal (5). The existing test of mattress condition is the Nurse Fist Test, consisting of the indentation of the mattress by both hands clasped together to determine hardness subjectively. This method is flawed by inter-operator variation, and ill-defined criteria for failure.

The authors have developed a portable objective measurement tool for the assessment of the fatigue condition of support surfaces ***(Patent Application GB 9905005.6)***, together with appropriate analysis algorithms to recognise failure. This report concerns the design and validation of the QUINCE Mattress-Tester.

PRINCIPLES OF OPERATION

The mattress-tester pictured in figure 1 attaches with a clamp to one side of the bed-frame. The operator stands on the opposite side and pushes the handles down with both hands, prompted by the interactive LCD display. A dumbell-shaped indentor (6) (consisting of two 150mm diameter x 40mm thick wheels, spaced 80mm apart) is driven down into the mattress. The device has the capacity to log force, displacement, and time continuously during a test cycle. These parameters are processed on-board using a proprietary algorithm to characterise the mechanical condition of the mattress. The results of this analysis are displayed on the LCD. Future models may incorporate a label printer to aid referencing of all mattresses tested.

QUINCE SCORE REFERENCED TO ACCELERATED FATIGUE

An accelerated fatigue rig was built in accordance with ISO 3385 (7) – the standard for fatigue of flexible cellular materials. A fresh Vaperm reversible mattress was chosen, and indented for 160000 cycles, and tested using the QUINCE mattress tester at intervals as indicated in figure 2.

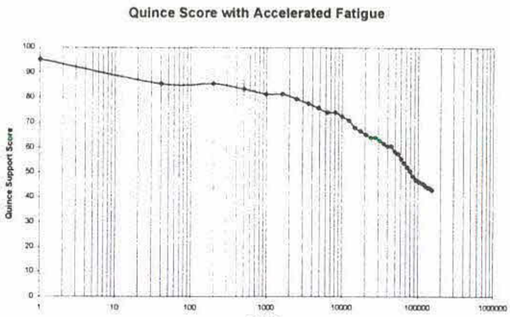


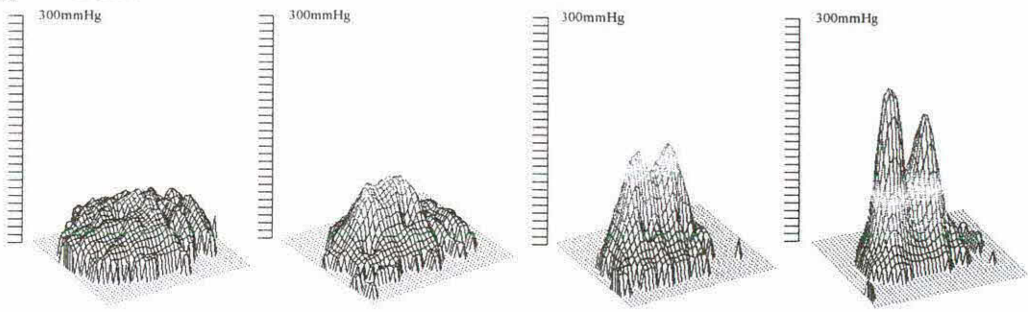
Figure 2

Degeneration of the mattress with increasing number of fatigue cycles can be clearly seen.

A Quince Support Score of 0 represents the behaviour that would be expected when there is no interface material. The Quince Support Score is a value developed by CDRI and is a function of both the force and displacement characteristics of the support surface.

QUINCE SCORE REFERENCED TO PRESSURE MAPPING ON A HEALTHY VOLUNTEER

Four mattresses were selected with a good spread of Quince Support Scores as measured using the device, ranging from a fairly new mattress with a score of 88 to a very fatigued 20-year old mattress with a score of 32. Each mattress was placed on a smooth floor, and a Tekscan pressure mapping device was placed underneath the centre of the mattress. A healthy volunteer was then asked to sit upright on the mattress in the region of the pressure mapper. Figure 3 shows the pattern of loading passing through the mattress to the floor for each of the four mattresses, together with its respective Quince Support Score. It can be seen from the pressure maps that the prominence of ischial loading passing through the mattress increases with increasing Quince Support Score.



Quince Support Score of 88 Quince Support Score of 56 Quince Support Score of 48 Quince Support Score of 32

Figure 3

QUINCE SCORE AND FIST TEST REFERENCED TO MATTRESS AGE

150 mattresses currently in use at the Royal National Orthopaedic Hospital, Stanmore, UK were tested using the Quince Mattress-Tester and the Nurse Fist Test. The Hospital Tissue Viability manager was asked to categorise each numbered mattress into 1 of 5 groups from good (1) to bad (5) using the fist test. Independently (and blindly), a CDRI operative tested each numbered mattress with the Quince Mattress-Tester, and a Quince Support Score was generated. A positive correlation

exists (R2= 0.74) between mattress age and Quince Support Score (Figure 4). This supports the expectation that age is a factor in the overall condition of a mattress. The correlation is not especially strong, as condition is also affected by many other factors. Age alone cannot be used as a failure criterion. There is poor correlation, however, between mattress age and the nurse fist test as depicted in Figure 5. Unless one accepts that age has no influence on mattress condition, these results suggests that the fist test is unreliable.

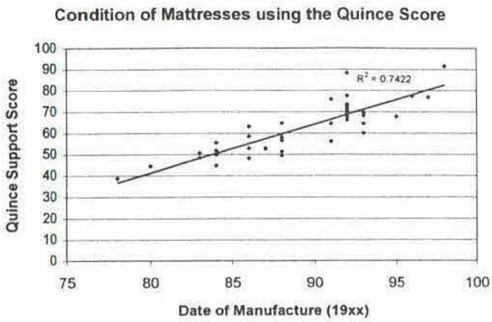


Figure 4

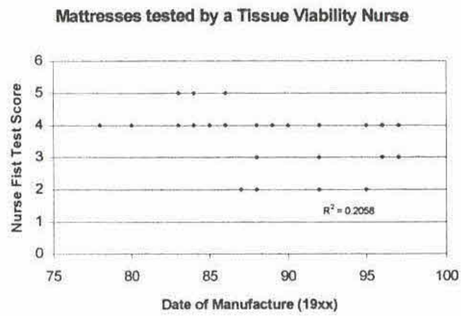


Figure 5

CONCLUSIONS

The QUINCE in-service mattress-tester is a portable, easy-to use, interactive device that quickly gives accurate information as to the condition of a mattress in a clinical setting. The device is sensitive in determining wear as a result of cyclic fatigue loading. Increasing Quince Support Score is reflected in increased penetration of discrete ischial loads through the mattress as measured using a pressure-mapping device. Quince Support Score correlates much better than the Fist Test to mattress age, although age alone is not a reliable measure of mattress fatigue. The Quince Support Score provides an objective and valid basis for a mattress replacement programme.

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FUNDAMENTALS OF INVENTING

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ABSTRACT

The Rehabilitation Engineering Research Center on Technology Transfer advances the methods of technology transfer through research, transforms technologies into products through development and facilitates the commercialization of new and improved assistive technology devices. This paper reviews the basic fundamental steps an inventor must take to insure confidentiality, uniqueness of product and design, and marketing viability. As Thomas Edison once said, *"Anything that won't sell, I don't want to invent."*

BACKGROUND

The RERC on Technology Transfer is a partnership of technical, marketing and consumer agencies experienced in assistive technology evaluation, transfer and commercialization. The partnership, led by the Center for Assistive Technology, University at Buffalo, includes the Western New York Independent Living Center, Aztech, Inc., and the Research Triangle Institute (1). Over the course of the last six years, the RERC has evaluated hundreds of Assistive Technology inventions from researchers and the general public.

APPROACH

As onerous as it may sound, once inspiration hits, an inventor needs to be a detail oriented individual. The inventor must become a detective in seeking out and documenting all the clues needed to put together a successful product puzzle. The following are a few tips on how to go about being a detail oriented inventor whose device makes it to market.

First, get a notebook and document the day that "the light bulb went on". The notebook must be of the bound type with pre-numbered pages. Your first dated, signed entry should be a description of your idea. All your notes, drawings, any information regarding your invention from the date of conception onward should be placed in this, your invention diary. It is at this point that you need to start being protective of your invention. You will need to draft a non–disclosure or confidentiality agreement that will have to be signed by others prior to your discussing your invention with them. Examples of agreements are readily available in many of the inventor books currently on the market (2). The logbook's initial entries will have be read, signed and dated by at least one, preferably two individuals whom you trust and who are not relatives or co-inventors. The United States patent system is one that is based on first to invent rather than on first to file. What this means to an inventor is that he or she must keep good and complete records to prove ownership in a court of law.

Next do your homework. You need to check to see if your product is already in the marketplace. You can begin this effort by searching the World Wide Web, catalogs, and stores. You need to focus on companies who make similar products to yours or who you would envision making your product. Visit retailers and professionals to learn how individuals currently address that function or need your device addresses with products currently in the market. Contact prospective users of your device, seeking information about how they, the consumer, currently address that function. At this stage your conversations with individuals or companies should focus on the function or need your product addresses, and not design information regarding your invention. Contact Abledata at 1-800-227-0216 or visit their website at www.abledata.com/index.htm. Abledata is a NIDRR sponsored project that maintains a database of over 25,000 Assistive Technology products. Abledata's database will provide you information on products currently in the marketplace performing the same function as your device.

During the RERC's existence, over 60% of the device submissions from inventors were re-inventions of existing products. It is best for an inventor to spend the time and effort at this stage to learn that their product currently exists in the marketplace, rather than expending resources on prototype development and attempted patenting of something that already has been invented (3).

Do your own preliminary patent search on the World Wide Web. Both the US Patent and Trademark Office and IBM have excellent sites for performing this task. The USPTO's website is www.uspto.gov and IBM's is www.patents.ibm.com. When performing this search use general, generic terms, not a marketing name you have given your device. For example: If your device is a lift that moves a person from a wheelchair to a bed, call it a patient lift, or a portable lift if it can be moved.

Researchers, under pressure to publish the findings of their work, sometimes rush to print a description of their invention in technical journals or magazines. You should be aware that publishing information regarding your invention begins a time bar of one year. During this one year period, you must file your patent or risk having your invention becoming public domain. That is you will no longer be able to patent your device after one year from date of publishing and anyone can use the information you disclosed. Public disclosure with the lack of intellectual property protection may prevent you from benefiting financially from your invention.

Ok, so there is nothing like your invention on the market. What next? Well, you need to look at components, materials and feasibility. Build a prototype and see if your idea is plausible. Concepts like the famous Star Trek transporter are great ideas but not all the components or exotic materials have been invented yet. A great deal of effort and time goes into building the prototype, but it is time and effort well spent when it comes to answering the questions potential manufacturing licensees will ask. And of course, if you do decide to patent your invention, a working prototype will assist tremendously with creating the drawings and describing the claims.

You now have documented your idea, verified it is unique, fabricated a prototype, and you are finished, right? Wrong. The work has only begun. Now you must prove its marketability by performing a market analysis which includes identification of the target market, market projections, market growth, distribution channels, and a competing product matrix benchmarking (contrasting) competing products versus the your device's characteristics. You may wish to obtain and include consumer input through focus groups held on the device to determine possible product enhancements and priority ranking of characteristics, purchase intent and price point (4). You need to be careful here though, as offering an unpatented product for sale starts the one year patentability time bar we discussed earlier. At this point you will wish to consider filing for a provisional or utility patent.

The next step is preparing this material for your target audience. The package you present must contain only useful information for the new business development manager who is going to read it. It must contain a one page Executive Summary highlighting the key information in your entire presentation packet. It is this summary that will pique the licensing executive's interest and compel them to read the balance of the document.

In addition to the Executive Summary, the package should include photographs or a videotape of the device in use, technical information including device features, human factors and environment, the results of your marketing analysis, and the consumer input you have received on your device. You should also provide the state of consumer satisfaction with existing products and the benefits or enhancements your device provides to consumers. Contents of this presentation packet have been discussed in more detail in a prior paper (5). All this data enhances your credibility with the companies you are approaching.

As you become an expert on your product, its' market, and the companies in your product's industry, you are becoming prepared to present your device to potential licensees. As a next step you need to identify the key decision makers in each of your targeted companies. These are the individuals you will be presenting your device to for licensing. Needless to say, if you are successful and the company presents a license agreement to you, you will need legal representation.

An option is to have an organization that is in tune with your target industry, which routinely presents products to those companies, represent you. Finding that organization will take some effort and creative digging on your part, but it is possible. Once finding that organization, they should handle the presentation, negotiation, and licensing of your invention. This group should monitor the sales of your product and process royalty payments to you. Your job is done. It's time to begin your next project!!!

DISCUSSION

We have communicated with hundreds of inventors and found that nearly all have failed to perform all of the fundamental steps. They may have performed some of the steps outlined, but not all. Now, they cannot understand why companies are not "beating a path to their door." It is of paramount importance for all inventors to follow a recipe for success. As in baking a cake, if the baker left out even one key ingredient, the cake won't rise or sell. Inventors must follow all the steps of the commercialization recipe or their product won't sell or worse yet, they will have spent their time and energy on something Thomas Edison warned against inventing.

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Quantifying Function and Outcomes (Topic 7)

DEVELOPMENT OF AN OBSERVATIONAL METHOD OF FORCE ASSESSMENT

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ABSTRACT:
Imbalance between the physical demands of work and the capabilities of the worker create barriers to employment. An important component towards overcoming these barriers is being able to quantify the physical attributes of work. Highly detailed and expensive instrumentation techniques are not practical for widespread use in occupational settings. Instead, observational techniques offer a higher level of efficiency and flexibility. This paper presents the development of an observational method of quantifying forceful exertions performed in occupational tasks.

BACKGROUND:
Imbalance between the physical demands of work and worker capability creates barriers to employment. Towards overcoming these barriers, the Rehabilitation Engineering Research Center (RERC) at the University of Michigan has adopted the model shown in Figure 1. This model incorporates a parallel assessment and comparison of worker capability and job demands. Job analysis entails evaluating the physical attributes of a job that may challenge the capability of the worker, including forceful exertions, repetition, awkward posture, contact stress, and exposure to vibration. Where job demand exceeds the capability of the worker, implementation of ergonomic and/or assistive technologies may be levied to achieve successful job placement.

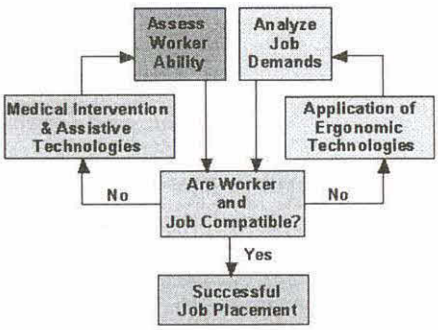

Figure 1. University of Michigan RERC model of job placement and overcoming physical work barriers

A critical component of the model is the quantification of physical work attributes. In terms of hand force, detailed instrumentation such as direct force measurement and electromyography exist, but require significant time and monetary resources. These techniques provide a lot of information about a small aspect of the job and don't offer the convenience and flexibility needed for widespread application in the field. Instead, a more pragmatic approach is to use observational methods of assessment. Observational rating involves assigning a number corresponding to the magnitude of the physical attribute. Subjective ratings such as these are easy to implement, but a criticism is that for what they offer in convenience, they lack in validity and reliability. To minimize their uncertainty and variability, Borg[1] maintains that subjective scales should be well anchored and clearly defined to increase "sameness" between users. In this spirit, Latko et al[2] developed a scale to assess hand repetition which uses well-defined criteria to anchor the rating and was shown to correlate well with objective measures such as cycle time and recovery time.

OBJECTIVE:
The objective of this research is to develop an observational rating scale of hand force. Such a scale will serve as a tool with which ergonomists and health care providers, alike, can assess the physical demands/capabilities of the job/worker. For the scale to be valid, ratings should correlate with

percent maximum voluntary contraction (%MVC), or the amount of force a person exerts relative to his or her maximum strength.

METHOD:
Hand force is produced internally and is inherently more difficult to rate using simple observation than more visible attributes of work such as repetition and posture. While characteristics such as bulging muscles and "jerking" may be seen with high levels of hand force, there are few conspicuous cues for submaximal levels. Thus, verbal descriptors, alone, may not suffice for estimating low to medium levels of hand force. The force requirements of many everyday activities will be measured and will serve as the benchmarks for rating force. To rate a job, the user will identify which benchmark activity most closely matches the force requirement of the job.

In rating a task for hand force, the rater must integrate the strength of the worker with the force requirements of the job. Consider two benchmark activities requiring F_1 and F_2 newtons of force, respectively. These forces fall along a "force axis" as shown below in Figure 2. Population strength data also lie on this axis, depicted by the pair of distribution curves. The 95th percentile male and 5th percentile female are reasonable boundaries of the population strength (represented by S_{M95} and S_{F5}). The appropriate force rating is then the ratio of force and strength. The upper limit is F/S_{F5} and the lower limit is F/S_{M95}. For example, suppose the peak force required to pull open a heavy drawer is 30 N. Using pull strength data from Mital and Kumar[3], the 5th percentile female and 95th percentile male strengths are approximately 126 and 645 N, respectively. In terms of the ten-point force scale, the peak force rating could range from 0.5 (30/645) for a strong male to 2.4 (30/126) for a weaker female. It is possible that some percentage of the population will not be able to meet the force requirements of a high force activity, such as with activity F_2 in Figure 2. In this case, the force/strength ratio would exceed one (i.e., greater than 100%MVC). However, the rating would have an upper bound of 10, based on the assumption that the only people who will perform that activity are those who possess the strength.

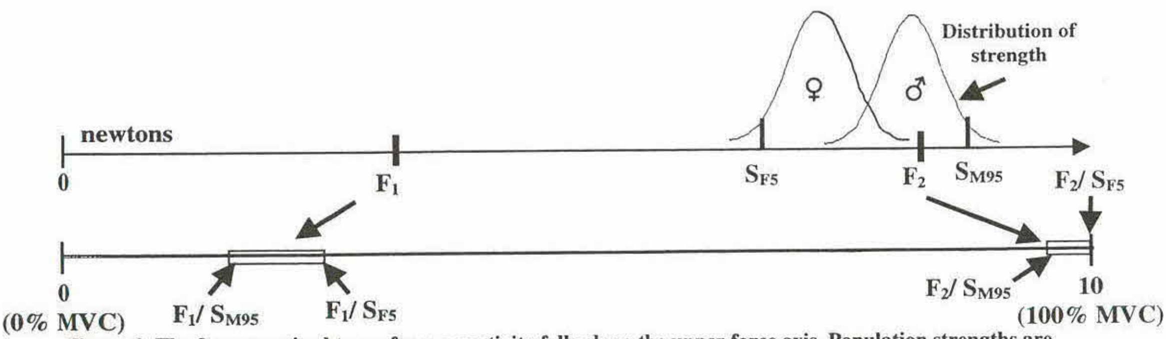

Figure 2. The force required to perform an activity falls along the upper force axis. Population strengths are depicted by the distribution curves. The range of force ratings is bounded by ratios of force and strength limits. The strength limits are defined as 5th percentile female and 95th percentile male.

Development of the force rating scale entails a survey phase to identify reference activities and a laboratory phase to measure the force required in performing these. The purpose of the survey is to determine common reference activities that users of the scale will relate to. As they perform exertions requiring "low," "medium," and "high" levels of force on a work simulation machine, participants are asked to list as many activities they can think of that they associate with the exertion. The purpose of using the work simulator is to stimulate the muscles and assist the subject in brainstorming. The levels of force have been selected to be within the range of upper percentile male strength, where low is less than 30%MVC, medium is between 30% and 70%MVC, and high is greater than 70%MVC for the male population. The simulated activities represent a wide variety of upper extremity exertions, including gripping, pinching, pressing, and creating torque. The participants are given a list of categories to stimulate thought, including "household chores," "kitchen work," "yard work," "office work," and "recreational activities." The tasks listed by the participants are then compiled in a database. A partial list of activities mentioned by participants to date is listed in Table 1.

Low (< 30%MVC)	Medium (30-70%MVC)	High (>70%MVC)
• Typing on a keyboard	• Turning on a faucet	• Lifting a heavy dumbbell
• Writing with a pen or pencil	• Opening a pickle jar	• Raking leaves
• Opening refrigerator	• Using pliers	• Scraping grill
• Brushing teeth	• Lifting a gallon of milk	• Doing a push-up or pull-up
• Driving	• Cutting bread	• Scraping ice off a windshield
• Opening a cabinet drawer	• Pushing open a door	• Carrying a case of bottled water
• Spray cleaning solution	• Opening a bottle of nail polish	• Moving furniture
• Volume adjustment on a stereo	• Unlocking a door with a key	• Sawing wood
• Using a stapler	• Vacuuming the floor	• Scraping paint
• Turning on/off alarm clock	• Using a can opener	• Starting lawn mower (rip cord)

Table 1. List of activities mentioned by participants during the survey phase.

Having identified a set of reference activities, the next step will be to determine what the actual force requirements are for each activity. Since this force will vary, each activity will be "sampled" several times and will be expressed as a range. For example, "opening a cabinet drawer" depends on many factors, including the weight of its contents and the friction in the bearings. These force data will then be combined with corresponding strength data to determine the appropriate range of force ratings for each activity. Video clips of the activities will also be prepared so users of the scale can view and compare them to the job being rated to determine the appropriate force rating.

DISCUSSION:

The rating scale will consist of dozens of activities, representing all types of upper extremity exertions. It is hoped the system will be augmented continually through the addition of activities as more data are collected on force requirements and population strength. The system offers health care practitioners and ergonomists a common tool with which to measure, in parallel, human capability and job demands. This is an important step towards understanding and overcoming the physical barriers to employment.

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INTELLIGENT SYSTEMS: TERMINOLOGY, TOOLS, AND APPLICATIONS FOR REHABILITATION/TELEREHABILITATION

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ABSTRACT

A brief review of intelligent systems terminology is given with applications in tele- and local rehabilitation. This is followed by a description of extant intelligent systems software tools. A sample intelligent system (neurofuzzy muscle force estimator) for use in tele- and local rehabilitation is discussed.

MOTIVATION: HOW CAN INTELLIGENT SYSTEMS HELP REHAB?

While intelligent systems (ISs) apply to many fields, they are potentially quite powerful in tele- and local rehabilitation: they offer added value by incorporating professional (e.g., clinical) expertise into an evaluative or assistive system. They may also potentially adapt themselves to the needs or abilities of a specific user [1]. The need for better intelligent systems tools for healthcare applications was identified as one of the top societal priorities at the recent Workshop on Home Care Technologies for the 21st Century [2].

INTELLIGENT SYSTEMS: TERMINOLOGY & TOOLS

Intelligent Systems: modeling human cognition to add "smarts" to hardware & software.

ISs handle ambiguous or incomplete data (rather than random/probabilistic); they can adapt (learn). "Intelligence" refers to low-level, human-like cognition rather than conventional artificial intelligence's (AI) symbolic approach [3]. Fuzzy logic, neural networks, and probabilistic reasoning are common techniques for building intelligent systems [1-4].

Expert Systems: capturing the knowledge of a human expert for others to use.

Conventional AI mimics human intelligence symbolically in language forms and rules; a knowledge base is constructed to store the information [4]. An expert system seeks to represent "if-then" decision-making of a human expert, given a narrow enough problem area and reasonably explicit knowledge.

Fuzzy Systems: flexibility for handling expert knowledge with nonlinear/vague/ imprecise data.

Crisp logic only allows discrete yes-or-no membership in a given set; fuzzy logic allows elements to assume partial membership. Chapter 2 of [4] illustrates the power of this: consider "tall" people, where "tall" implies "height over 6 feet." In a classical set, "6 feet" denotes a crisp boundary: someone 6.001 feet tall is included, but someone 5.999 feet tall is not. Fuzzy logic gives both individuals partial membership—an intuitive approach to natural imprecision. Membership values in a fuzzy set may be discrete or continuous along the range [0 1].

Fuzzy systems employ fuzzy logic through inference: "if x is A, then y is B." Classical crisp inference is a subset of fuzzy inference. Consider this inference: "if a tomato is red, then it is ripe." The degree with which the tomato satisfies "redness" (its membership value along [0 1]) dictates its membership in the set "ripeness." Expert systems and control systems, such as for functional electrical stimulation [6], are frequently implemented as fuzzy systems.

Neural Networks: allowing "learning" with context of nonlinear/vague/imprecise data.

Artificial neural networks consist of processing elements ("artificial neurons") connected to each other in layers. Elements in a layer connect with elements in the same or other layers via weights. The weights are adjusted as the network learns; they thus act as the network's long-term memory. Learning can be supervised (the system adjusts its weights until a given input's output matches the desired output), unsupervised (the system adjusts its weights until it has organized itself), or reinforced (the system adjusts its weights based on feedback from an evaluative "critic"). Each method of learning has several well-established implementation algorithms.

Like classical optimization, neural nets feature a "plant" to optimize (e.g., the network itself); constraints; goals; and algorithms for reaching goals while obeying constraints. Like fuzzy systems, neural nets offer design flexibility and robustness to nonlinearity and imperfect data. Unlike fuzzy systems, neural nets can learn/adapt by changing internal weights. However, human expert knowledge is easily designed into a fuzzy system, yet this proves difficult for neural nets. Neural nets can be used to help other intelligent systems adapt/learn, but they are often used to implement models (e.g., muscle) themselves [7].

Neurofuzzy Systems: learning & expert knowledge in context of nonlinear/vague/imprecise data.

Neurofuzzy systems offer the best of both. The configuration can be fuzzy-neural (e.g., fuzzy neurons) or neural-fuzzy: one possibility would be a fuzzy expert (e.g., the muscle force estimator above) which uses a neural network to tune its membership parameters. Other examples include fuzzy inference systems implemented as neural nets, like FALCON [3] (the Fuzzy Adaptive Learning COntrol Network) and ANFIS [4] (the Adaptive Neuro Fuzzy Inference System).

Intelligent Systems Tools

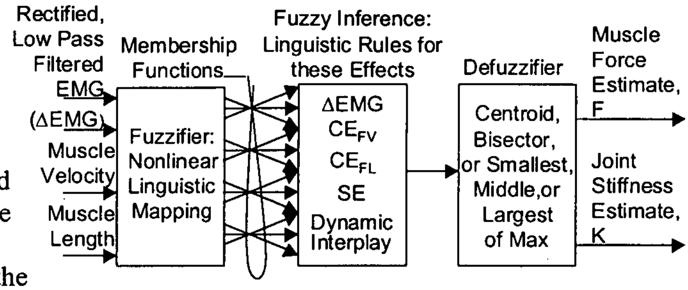
Many software packages are available to an IS designer: some, freely downloadable from the internet; others, commercially available. Some available packages:

- CLIPS (free): http://www.ghg.net/clips/CLIPS.html
- Jess (free): http://herzberg.ca.sandia.gov/jess/
- Fuzzy Jess (free): http://ai.iit.nrc.ca/IR_public/fuzzy/
- Fuzzy CLIPS (free): http://ai.iit.nrc.ca/fuzzy/fuzzy.html
- MATLAB (commercial): www.mathworks.com

NEUROFUZZY EXPERT APPLICATION—MUSCLE FORCE ESTIMATOR

A rehab clinician (e.g., physiotherapist) could benefit from an expert system which takes electromyogram (EMG) data and estimates muscle force and joint stiffness from rules capturing the properties of a nonlinear dynamic muscle model. This framework also allows inclusion of other clinically-oriented rules (e.g., to identify specific pathologies or rehabilitative progress).

To combine clinical expert knowledge with the Hill muscle model [5], a neurofuzzy expert muscle force estimator, which uses a neural net for tuning membership function parameters, is being developed (see Figure). The goal is to provide accurate estimates of muscle force and joint stiffness from velocity, length, EMG, and change in EMG by using the nonlinear physical properties of muscle neglected by other methods (e.g., smoothed, rectified EMG alone). The fuzzy muscle force estimator will be part of a clinician-assistant expert system that will take the force estimates and offer intelligent suggestions (e.g.,



"movement behavior is pathological"; "improvement is occurring"; or whether a certain assistive technology enhances performance).

MATLAB v. 5.2 is being used to develop this expert system. The fuzzy GUI sufficed for simple rules, but there was no access to the membership function parameters for neural net tuning. Thus, a more complete fuzzy inference engine is being developed to support critical neurofuzzy aspects of development; to allow more sophisticated/intuitive rule constructions (fewer rules through membership function combinations and hedges); and to allow complete control over the internal fuzzy mathematics (helpful, although MATLAB supports user-added membership functions and fuzzy operations). For cases MATLAB can handle, the new fuzzy inference engine has produced identical results. While currently coded in MATLAB for verification against MATLAB fuzzy GUI results, it is expected to be re-coded (e.g., in Java or C++) with its own GUI, and made available to other researchers as needed.

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A FINITE ELEMENT MODEL OF THE FOREFOOT REGION OF ANKLE-FOOT ORTHOSES FABRICATED WITH ADVANCED CARBON COMPOSITE MATERIALS

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ABSTRACT

This paper discusses the development of a finite element model (FEM) of the forefoot region of ankle-foot orthoses (AFOs), or rigid ankle braces, that are constructed of advanced composite materials. FEM can be used to help develop new AFO designs and determine their feasibility before clinical trials. FEM models of two different AFO forefoot region designs were modeled. The FEM models had mean errors below 20% for the load versus deflection properties. Also, the model predicted that one AFO design allowed 50% more deflection at the same load, which correlated with experimental results by 75 percent.

INTRODUCTION

There is a need for strong yet lightweight ankle-foot orthoses (AFOs), or ankle braces, to provide additional support and maintain stability during standing and ambulation. The conventional material used is polypropylene, a thermoplastic that can be easily molded to a positive mold of a patient's limb and easily postformed (1). However, for many AFO users, polypropylene AFOs are too bulky and heavy, and offer only limited rigidity in some planes during ambulation (2).

Researchers, including those at Rancho, have begun to explore using composite materials as an additional material for AFO construction (2,3) (Figure 1). At Rancho, a team has been studying the feasibility of AFOs using pre-impregnated (prepreg) advanced composite carbon, aramid and glass fibers (2), as seen in figure 1. Orthoses built of advanced composite materials- highly engineered materials designed initially for the aerospace industry-, show promise. The advanced composite AFOs have a higher strength-to-weight ratio than polypropylene AFOs, as a result of significantly different material properties. This has allowed researches and orthotists to fabricate novel AFO designs (2).

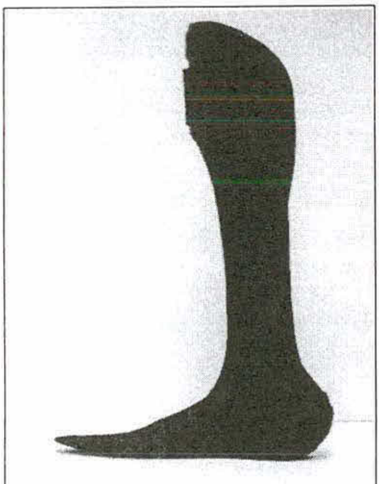
Figure 1: Full-Toe Carbon Composite AFO

Only recently has FEM been used to assess thermoplastic AFOs (4), perhaps due to challenges of modeling thermoplastic materials and a complex shape such as an AFO. FEM has not been used to model composite AFOs, which have an additional difficulty in the directional properties of the composite materials.

PURPOSE:

Recent advances in FEM software modeling programs have allowed the modeling of composites and laminates (which have a high length to thickness ratio) as a 2-D surface with laminate properties have. Using these new programs, an AFO can be modeled as a 2-D laminate shell instead of a 3-D solid. By addressing these limitations in order to improve the computer models, FEM may prove to be a useful tool in the design of orthotics, potentially reducing time and cost in the design and testing of new orthosis designs.

METHOD

The FEM model was generated on a PC using the MacNeal-Schwendler Corporation (Los Angeles, CA) MSC's Patran finite element analysis software package. The analysis of the FEM model was done on MSC's Nastran package. Both software packages were used on a Windows NT workstation. The models were built using only plain weave and braided prepreg fabric materials. The models were 2-D surface laminate models (5). For each surface, the appropriate materials, layers, and orientations of the carbon plain weave fabric and carbon braid fabric were assigned.

The plain weave and braid fabrics were modeled as 8 layers of laminates, at alternating orientations. Each laminate layer is 1/8th the original ply thickness for the material being modeled (plain weave fabric = 0.206 mm / fabric layer, braid fabric = 1.206 mm / fabric layer).

Two partial AFOs consisting of the forefoot region and side sections were manufactured to test the computer models created. After the AFOs were created, the dimensions of the AFO were measured to create the computer model. The dimensions were taken from a fabricated AFO, since it is difficult to create composite AFOs to precise dimensions due to the complex contours of the positive cast and custom lay-up procedure used to create each AFO. The FEM software was used to create a mesh on each surface, with each mesh element with an edge length of 4 mm (Figure 2).

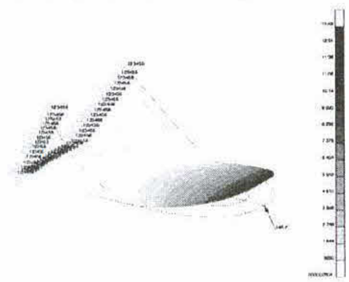

Figure 2: Deflected FEA model of forefoot region of an AFO.

After the AFOs were manufactured, they were tested in a stiffness jig, which applied a vertical load to the tip of the AFO at a 30^{o} orientation to the vertical axis. This simulates the load condition at the terminal stance of gait (6). The experimental results (load vs. deflection) were compared to the expected results from the FEM models.

RESULTS

The experimental testing showed that the model had an error less than 20% for all the loads applied (Tables 1 and 2).

Load	Model Deflection	Experimental Deflection	Error
58 N	5.45 mm	5.08 mm	7.3%
102 N	9.64 mm	9.78 mm	1.4%
146 N	13.83 mm	15.24 mm	9.3%
191 N	18.20 mm	21.84 mm	16.7%
236 N	22.21 mm	26.04 mm	14.7%

Table 1: Design #1 Results

Load	Model Deflection	Experimental Deflection	Error
58 N	8.38 mm	8.64 mm	3.0%
102 N	14.79 mm	17.91 mm	17.4%
146 N	21.21 mm	25.91 mm	18.1%

Table 2: Design #2 Results

DISCUSSION

This research attempted to create a working FEM model of the forefoot region of an AFO built with carbon composite materials. Two different AFO forefoot region designs were created for testing. Each design was modeled on the FEM software package using the mechanical properties calculated earlier in this study. The AFO forefoot region models had an error under 20% for the load/deflection response

The models also showed one advantage of using FEM in analyzing different AFO designs. The FEM models predicted that the second design would deflect 54% more than design #1 under the same load. This matched with the experimental results. This shows that the computer model was able to predict how changes in the geometry and lay-up can affect AFO performance. Knowing this, a small database could be established of several different designs. Then, as new designs are developed, they could be modeled and compared to this database to predict how they behave relative previously modeled designs in the database.

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APPLICATION OF A COMMERCIAL DATALOGGER FOR REHABILITATION RESEARCH

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ABSTRACT
To achieve validity in rehabilitation clinical research, data should optimally be collected while subjects are engaged in activity representative of daily living. This paper describes modifications made to a commercial, battery-powered datalogger so that the logger could be mounted on personal wheelchair and used to record the subject's propulsion activity at home. The resulting system has been sent home with one subject for a two week period and provided an accurate, unbiased log of this individual's daily wheelchair usage including time in motion, distance covered, and velocities. Data can be quickly transferred from the datalogger's memory chips to a desktop PC and be analyzed and graphed with MATLAB.

INTRODUCTION
When rehabilitation research takes place in a laboratory, subjects are aware that data is being collected and may perform in an atypical manner - not as they would if the same activity took place at home. This threat to research is referred to as the Hawthorne effect (1). For quantitative data collection, a portable, battery powered datalogger can sometimes be employed. This device travels with the subject and silently and independently records the desired data. Commercial one board dataloggers (2)are available that will operate for several weeks on a nine volt battery and can record up to 400,000 bytes of data on non-volatile memory chips. In an ongoing research project, the Human Engineering Research Laboratories successfully developed a weather-proof datalogger that unobtrusively attaches to manual and electric powered wheelchairs and records the subjects' movement activity. The client does not have to switch the datalogger on and off. The datalogger automatically "wakes up" whenever the chair is moved and automatically "hibernates" to conserve power whenever the chair is stationary.

METHODS
The goal of this particular research was to determine whether the power assist units on the Yamaha II manual wheelchair would encourage increased voluntary usage by consumers over their own traditional manual wheelchairs. An invisible, unobtrusive data logging system was required that would operate unattended for up to 14 days during a take-home trial.

The TFX-11 datalogger/controller is a single board computer with two processors; a Motorola 68HC11F1 and a PIC16C62. The PIC processor has extremely low current consumption and during testing operated up to nine days on a single lithium nine volt battery. The PIC processor will "wake up" the 68HC11F1 when data needs to be collected and stored. The system has 128 K of static

RAM for programs and 472 K of serial flash EEPROM for data storage. The system software includes a BASIC interpreter which allows fast program development.

Movement sensing components were developed that can be quickly mounted on a variety of subjects' wheelchairs. Three permanent magnets are attached with slotted machine screws and pinch nuts to three spokes equally distributed around the perimeter of one rear wheel. A reed switch is mounted on the wheelchair frame underneath the path of the magnets as depicted in Figure 1.

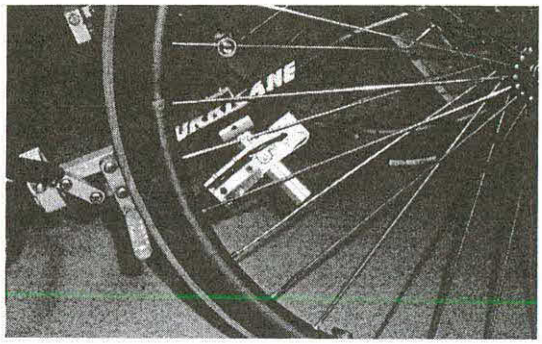

Figure 1. Magnet and reed switch sensor

A machined aluminum enclosure was created with Feature CAM (3) to protect the TFX 11 computer boards from weather and impact damage (Figure 2). The box utilizes an O ring seal and has a separate chamber to retain two nine volt batteries. Split ring clamps on the exterior of the box provide convenient, reliable mounting to a wheelchair frame tube.(Figure 3)

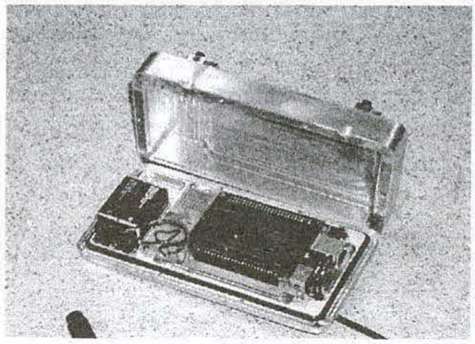

Figure 2. Machined aluminum enclosure

A shielded cable is used to convey the reed switch status to the digital I/O board of the TFX-11. An RC network was used as a low pass filter to exclude switch bounce and other signals over 10Hz. The authors felt that the nine pin DIN connector provided by Onset computer for parallel data transfers might fail with repeated cable insertions so it was replaced with a 10 pin modular jack.

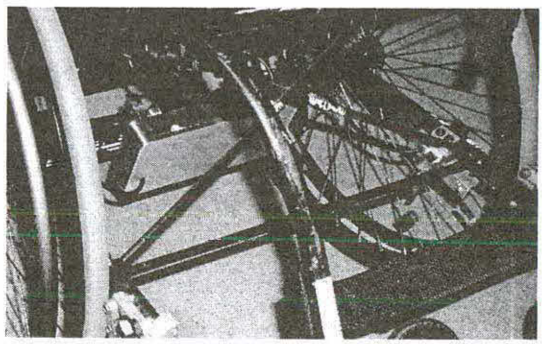

Figure 3. Enclosure installed on subject's wheelchair

The software program for data collection was written in BASIC. During periods of inactivity only the PIC microcontroller is active. When a magnet passes over the reed switch, a pulse is transmitted to digital input #1. The main processor is brought out of hibernation and a time stamp is recorded in non volatile memory. A timestamp consumes only four bytes so over 100,000 time stamps can be recorded.

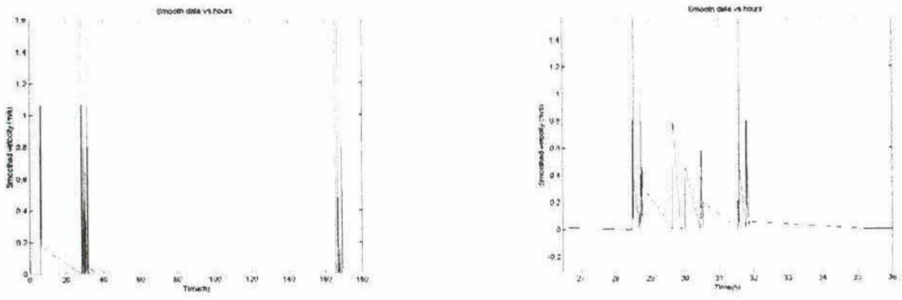

Figure 4. Velocity graphs generated by MATLAB (4)

RESULTS

Figure 4 illustrates some typical activity graphs that can be reduced from the time stamp files. The left graph covers activity over a one week (168 hours) period. The subject used her wheelchair on the second and seventh day. The graph on the right provides more detail on the sequence of movements that took place on the second day. Actual totals for this week were: Average velocity .85 m/s; Total distance 1350 meters; Total time in motion 7.64 hours

DISSCUSSION/CONCLUSION

Initial results indicate the Datalogger is reliable and accurate at slow chair speeds. One problem yet to be resolved is resolution. The current time stamps are only recorded to the nearest second. At higher wheelchair velocities, two magnets can pass over the reed switch in less than a second causing a pair of identical time stamp. The calculated velocity will suddenly drop to zero in the middle of a bout when this happens. The authors are smoothing the data in MATLAB to remove these errors. A better long term solution will be to change the recording software to include tenths of seconds.

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3. Feature CAM (CNC milling machine software) Engineering Geometry Systems 275 East South Temple, Suite 305, Salt Lake City, UT 84111
4. MATLAB (data reduction and graphing software) MathWorks, Inc., 24 Prime Park Way, Natick, MA 01760

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WHEELCHAIR SEATING AND POSITIONING OUTCOMES IN THE ELDERLY NURSING HOME POPUILATION

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ABSTRACT

The purpose of this study was to investigate whether or not the elderly who reside in nursing homes and sit in a wheelchair for 6 hours a day or longer, benefit from a custom fit wheelchair and seating system. Through an experimental design 24 people (60-98 years) were randomized into two groups (intervention & control), and they received a new wheelchair, cushion, and custom seat back. All were given four outcomes tests at specific time intervals. The administration of the Rand SF 36, QUEST, wheelchair mobility, and postural stability tests were performed to compare current systems with custom prescribed systems.

RESEARCH QUESTION

The objective of the study was to investigate the level of function and quality of life in elderly persons who use manual wheelchairs. Four hypotheses were established to enable us to measure independent mobility, satisfaction with assistive technology, posture, and quality of life. The hypotheses are that the intervention group:

1. *Will have less difficulty independently propelling their wheelchairs.*
2. *Will express greater satisfaction with their assistive devices.*
3. *Will exhibit greater postural stability.*
4. *Will report higher quality of life.*

METHODS

Groups: Subjects were randomly divided into two experimental groups, intervention and control. The intervention group received their new wheelchair three months before the control group. See table #1.

Subjects: 34 people using an experimental design were selected from 3 different nursing home facilities. They gave written consent to participate in the study. 27 were female and 7 were male. The mean age of the participants was 82.4 ± 9.8 years. 10 subjects dropped out due to death, change of health status, etc. 24 of the subjects completed all phases of the study. Upon completion of the study there were 12 controls and 12 interventions.

	Visit #1	Visit #2 (3 Months)	Visit #3 (3 Months)
Intervention	Old w/c	New w/c	New w/c
Control	Old w/c	Old w/c	New w/c

Table 1: Intervention & Control group time frame

* Intervention: Visit #2 is 3 months after receiving new wheelchair
* Control: Visit #3 is 3 months after receiving new wheelchair

Data Collection: Quebec User Evaluation of Satisfaction with Assistive Devices (QUEST) was interactively administered to all of the subjects at visit 1, 2 & 3 (1). The subjects rated (1-5 scale) different characteristics regarding "satisfaction" levels with their old and new wheelchair/seating intervention.

Rand SF-36 general health status questionnaire was interactively administered to all of the subjects at visit 1, 2 & 3 (2). The subjects responded to questions by sorting through the given list of possible answers and choosing the one that best describes they way they felt at that point in time.

Wheelchair Mobility: Subjects were asked to manually propel their wheelchairs. A method of testing was determined by professionals at the University of Pittsburgh for comparing w/c mobility differences between test phases. There were two separate tests, Test 1 and Test 2. Test 1 was a timed course on a level tile surface with the straight distance of 25 feet. Test 2 was a timed course on a level tile surface of 10 feet straight, 90-degree right turn, and then 15 feet straight for a total distance of 25 feet. The subjects performed Test 1 and Test 2 three times at each three-month interval.

Posture Stability: Subjects were asked to physically reach forward and lateral while situated in their wheelchairs. The method of testing was determined by professionals at the University of Pittsburgh and adapted from Axelson and Chesney (3). The subjects' most dominant arm was measured. Subjects had their feet placed on a telephone book. Every subject had their arms placed on their laps-not the arm rests. C-7 and the seat back were marked with tape so the subjects returned to neutral after each lateral reach. The restraining devices were taken off. After a detailed explanation and demonstration, the subjects performed the two reach tests (Fig. 1 & 2).

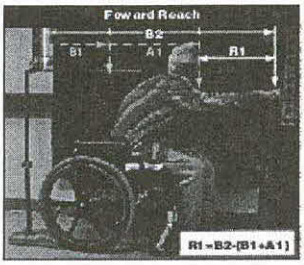

Fig. 1 (Forward Reach)

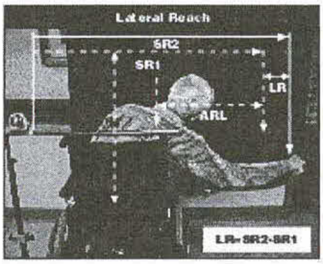

Fig. 2 (Lateral Reach)

RESULTS

The results for the four areas of testing were calculated and analyzed. The results of the four phases are in Tables 2-4.

DISCUSSION

Analysis of the differences between a current wheelchair and a custom prescribed wheelchair and seating system statistically and clinically show that an elderly wheelchair user will benefit from a custom prescription. The intervention groups did independently propel their wheelchairs easier than the control group. Overall the subjects in the custom fitted wheelchairs and seating systems became more mobile and generally more satisfied with their assistive technology (QUEST). The results that the subjects became faster in the new wheelchair are statistically significant ($p < 0.05$).

The two measures of postural stability do show differences in wheelchairs and seating systems. The subjects' forward reach did increase in the new intervention but the lateral reach appeared to decrease. The increase in forward reach is probably the result of feeling more secure because the new seating system is properly supporting the pelvis, thighs, and torso. The decrease in lateral reach can be attributed to subjects being prescribed contoured seat backs. Statistical analysis shows that the subjects who received a contoured seat back were more limited than those who received a planar seat back.

Analysis of the Rand SF-36 shows that the intervention group did report a higher quality of life than the control group in the area of role and social functioning. These results are also statistically significant ($p < 0.05$). Overall, all of the subjects benefited in some way or another from receiving a custom fit wheelchair and seating system.

As well as the statistical results reported there are a number of clinical observations that support our hypotheses. Both the subjects and caregivers were better educated as a result of this study. Subjects felt they were more knowledgeable with the decision of choosing assistive technology, and the quality of wheelchair and seating provisions increased in all 3 nursing homes over the two years of this project.

	Interv/Control	Visit #1 (Baseline Time)		Visit #2 (change)		Visit #3 (change)	
Test #1(25ft)	Intervention	Old w/c	41.5 + 53.5	New w/c	-4.3	New w/c	-1.3
	Control	Old w/c	47.9 + 35.5	Old w/c	0.3	New w/c	-16.8
Test #2 (10ft,rt turn, 15ft)	Intervention	Old w/c	51.4 + 53.4	New w/c	-5.2	New w/c	-4.0
	Control	Old w/c	69.4 + 60.9	Old w/c	-2.8	New w/c	-18.4

Table 2: Independently propelling wheelchairs for Test 1 & 2. A comparison of intervention vs. control groups.

	Visit #1 (Global Score)		Visit #2 (change)		Visit #3 (change)	
Intervention	Old w/c	3.72	New w/c	+0.93	New w/c	+0
Control	Old w/c	3.14	Old w/c	-0.42	New w/c	+2

Table 3: QUEST: Rating global satisfaction. Comparing a change in satisfaction between the intervention & control groups regarding their new & old assistive technology (manual wheelchair). Scale is 1-5 (1= not satisfied at all, 5 very satisfied).

	Interv/Control	Visit #1 (Baseline)		Visit #2 (change)		Visit #3 (change)	
Lateral Reach	Intervention	Old w/c	259 + 58.9	New w/c	-22.0	New w/c	-13.4
	Control	Old w/c	237 +68.7	Old w/c	9.8	New w/c	-8.3
Forward Reach	Intervention	Old w/c	272 + 106	New w/c	18.8	New w/c	22.9
	Control	Old w/c	276 + 131	Old w/c	-19.9	New w/c	39.5

Table 4: Posture: Postural Stability. Comparing forward & lateral reach lengths in the old & new wheelchairs between the intervention & control groups. Measurements were recorded in millimeters.

	Interv/Control	Visit #1 (baseline)		Visit #2 (change)		Visit #3 (change)	
Role Functioning	Intervention	Old w/c	68.1	New w/c	+20.0	New w/c	-8.33
	Control	Old w/c	64.3	Old w/c	-6.25	New w/c	+11.4
Social Functioning	Intervention	Old w/c	81.9	New w/c	+7.5	New w/c	-9.38
	Control	Old w/c	80.4	Old w/c	-18.8	New w/c	+13.5

Table 5: Rand SF-36: Quality of life. Comparing role & social functioning in the old & new wheelchairs between the intervention and control groups.

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IS AN ITEM GOOD OR BAD? SELECTING THE BEST SUBSET OF ITEMS FROM THE ORIGINAL VERSION OF THE QUEST

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ABSTRACT

The Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) is an outcome assessment tool designed to measure satisfaction with assistive technology in a structured and standardized way. The purpose of this paper is to present the result of an analysis of the 24 items comprising QUEST and to explain how a subset of 12 items demonstrating optimal measurement performance was selected. The construction of tests with minimal length that yield reliable and valid scores is an important issue in the assessment of outcomes.

BACKGROUND

Etymologically, the word 'satisfy' means make enough. In appearance, the concept of satisfaction seems quite simple and easy to understand. However, from a theoretical point of view, it is rather complex. Although it is approached as a multidimensional concept, there is to date little agreement about the factor structure of satisfaction measures. Satisfaction is also an arbitrary concept that can mean different things to different people. Based on literature reviews of empirical satisfaction studies and theoretical frameworks (1), satisfaction as defined in QUEST refers to a person's critical evaluation of specific characteristics of the assistive technology device. Individual expectations, perceptions, attitudes and personal values affect this assessment.

In 1997, the RESNA Conference was held under the theme 'Let's Tango-Partnering People and Technology'. The subject of one presentation was the construction and the development of the original QUEST (2). The main features of this instrument assessment were as follows. Firstly, it was comprised of the 24 items (listed in Table 1). Secondly, it was created in a 'card-playing' format and the assessment materials were presented as a kit. This way, people unable to write or see clearly were not excluded from participating to the evaluation. Thirdly, the items were rated twice by the users. Using a specific classifying task, the user was firstly asked to rate the degree of importance he or she would attribute to the individual items. By doing so, individual potential differences were accounted for in the definition of the satisfaction concept. After that, there was another interactive task during which the user was asked to rate his or her satisfaction with all of the variables.

Since then several studies were conducted to assess the measurement properties of the original QUEST, both at the item and at the test level (1). It was necessary to act upon the obtained results and improve the tool.

OBJECTIVE

In test construction, an ultimate goal is to develop a test of minimal length that will yield scores with the desired degree of reliability and validity for the intended uses. Typically, this is accomplished by field selecting a large pool of items and selecting a subset of items from the pool that makes the greatest contribution in regard to precise indicators. The objectives of this study were to examine if there is a subset of items comprised in the QUEST that demonstrate optimal validity and reliability and to assess the factorial structure of the satisfaction concept being measured.

METHOD

Six measurement properties were identified as highly relevant for the item analysis. These included: (i) general acceptability; (ii) content validity, reflecting the importance to device users and to professionals; (iii) criterion validity, based on correlation with global satisfaction; (iv) contribution to internal consistency; (v) test-retest stability; (vi) sensitivity, with respect to the amount of variability in scores. Factorial analyses were performed to refine the item selection and explain how items tend to cluster together in a meaningful way with respect to the satisfaction concept. Principal Axis Factoring (PAF) is the most widely used method of factor extraction for explaining common variance and it was used in this study.

Data from three sources were used in the item selection process: a Montreal sample (n=158), a Dutch sample (n=253) and data derived from a previous International Content Validation Study (3).

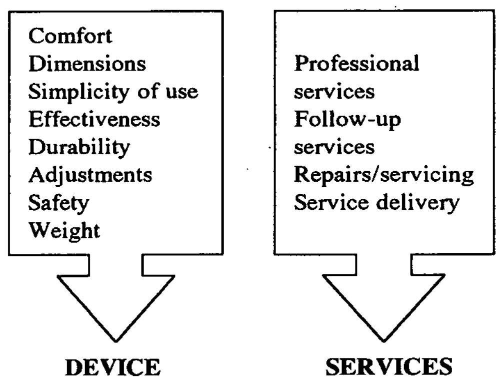
RESULTS

The 24 items comprised in the original version of the QUEST did not perform equally well against the six measurement properties. Some items (n=11) clustered in the upper part of Table 1 consistently showed desirable measurement properties. It was quite obvious that they were to be kept within the evaluation. On the opposite, another group of items (n=10) consistently has less than desirable measurement properties. It only made sense to remove them from the evaluation. For the few remaining items (n=3), inclusion or exclusion was decided by examining the internal consistency and the factorial composition of the whole scale. The best subset is comprised of 12 items.

Table 1: Items Performance with Respect to Measurement Properties

Good ratings	Comfort	Safety
	Dimensions	Service delivery
	Professional services	Effectiveness
	Follow-up services	Repairs/servicing
	Simplicity of use	Durability
	Adjustments	
Both good and bad ratings	Weight	
	Multi-purposefulness	
	Transportation	
Bad ratings	Maintenance	Cost
	Training	Effort
	Device compatibility	Motivation
	Appearance	Reaction of others
	Installation	Social circle support

Figure 1: QUEST Factorial Composition



The results of the factorial analysis revealed that the underlying structure of satisfaction with assistive technology consists of two dimensions. As shown in Figure 1, the first dimension is related to the DEVICE and comprises eight items. The second dimension is associated with the SERVICES and includes four items. This solution accounted for 39.3% of the common item variance and for 48.4% of the total items variance (based on Principal Components Analysis). The main advantage of having the items grouped this way is the ability to get an aggregated score within each dimension and to increase the usefulness of the data obtained from the device users.

percent maximum voluntary contraction (%MVC), or the amount of force a person exerts relative to his or her maximum strength.

METHOD:
Hand force is produced internally and is inherently more difficult to rate using simple observation than more visible attributes of work such as repetition and posture. While characteristics such as bulging muscles and "jerking" may be seen with high levels of hand force, there are few conspicuous cues for submaximal levels. Thus, verbal descriptors, alone, may not suffice for estimating low to medium levels of hand force. The force requirements of many everyday activities will be measured and will serve as the benchmarks for rating force. To rate a job, the user will identify which benchmark activity most closely matches the force requirement of the job.

In rating a task for hand force, the rater must integrate the strength of the worker with the force requirements of the job. Consider two benchmark activities requiring F_1 and F_2 newtons of force, respectively. These forces fall along a "force axis" as shown below in Figure 2. Population strength data also lie on this axis, depicted by the pair of distribution curves. The 95th percentile male and 5th percentile female are reasonable boundaries of the population strength (represented by S_{M95} and S_{F5}). The appropriate force rating is then the ratio of force and strength. The upper limit is F/S_{F5} and the lower limit is F/S_{M95}. For example, suppose the peak force required to pull open a heavy drawer is 30 N. Using pull strength data from Mital and Kumar[3], the 5th percentile female and 95th percentile male strengths are approximately 126 and 645 N, respectively. In terms of the ten-point force scale, the peak force rating could range from 0.5 (30/645) for a strong male to 2.4 (30/126) for a weaker female. It is possible that some percentage of the population will not be able to meet the force requirements of a high force activity, such as with activity F_2 in Figure 2. In this case, the force/strength ratio would exceed one (i.e., greater than 100%MVC). However, the rating would have an upper bound of 10, based on the assumption that the only people who will perform that activity are those who possess the strength.

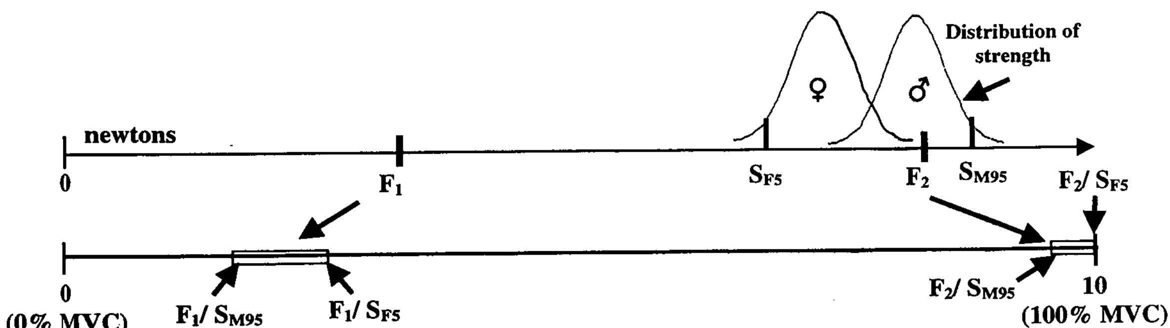


Figure 2. The force required to perform an activity falls along the upper force axis. Population strengths are depicted by the distribution curves. The range of force ratings is bounded by ratios of force and strength limits. The strength limits are defined as 5th percentile female and 95th percentile male.

Development of the force rating scale entails a survey phase to identify reference activities and a laboratory phase to measure the force required in performing these. The purpose of the survey is to determine common reference activities that users of the scale will relate to. As they perform exertions requiring "low," "medium," and "high" levels of force on a work simulation machine, participants are asked to list as many activities they can think of that they associate with the exertion. The purpose of using the work simulator is to stimulate the muscles and assist the subject in brainstorming. The levels of force have been selected to be within the range of upper percentile male strength, where low is less than 30%MVC, medium is between 30% and 70%MVC, and high is greater than 70%MVC for the male population. The simulated activities represent a wide variety of upper extremity exertions, including gripping, pinching, pressing, and creating torque. The participants are given a list of categories to stimulate thought, including "household chores," "kitchen work," "yard work," "office work," and "recreational activities." The tasks listed by the participants are then compiled in a database. A partial list of activities mentioned by participants to date is listed in Table 1.

Low (< 30%MVC)	Medium (30-70%MVC)	High (>70%MVC)
• Typing on a keyboard	• Turning on a faucet	• Lifting a heavy dumbbell
• Writing with a pen or pencil	• Opening a pickle jar	• Raking leaves
• Opening refrigerator	• Using pliers	• Scraping grill
• Brushing teeth	• Lifting a gallon of milk	• Doing a push-up or pull-up
• Driving	• Cutting bread	• Scraping ice off a windshield
• Opening a cabinet drawer	• Pushing open a door	• Carrying a case of bottled water
• Spray cleaning solution	• Opening a bottle of nail polish	• Moving furniture
• Volume adjustment on a stereo	• Unlocking a door with a key	• Sawing wood
• Using a stapler	• Vacuuming the floor	• Scraping paint
• Turning on/off alarm clock	• Using a can opener	• Starting lawn mower (rip cord)

Table 1. List of activities mentioned by participants during the survey phase.

Having identified a set of reference activities, the next step will be to determine what the actual force requirements are for each activity. Since this force will vary, each activity will be "sampled" several times and will be expressed as a range. For example, "opening a cabinet drawer" depends on many factors, including the weight of its contents and the friction in the bearings. These force data will then be combined with corresponding strength data to determine the appropriate range of force ratings for each activity. Video clips of the activities will also be prepared so users of the scale can view and compare them to the job being rated to determine the appropriate force rating.

DISCUSSION:

The rating scale will consist of dozens of activities, representing all types of upper extremity exertions. It is hoped the system will be augmented continually through the addition of activities as more data are collected on force requirements and population strength. The system offers health care practitioners and ergonomists a common tool with which to measure, in parallel, human capability and job demands. This is an important step towards understanding and overcoming the physical barriers to employment.

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INTELLIGENT SYSTEMS: TERMINOLOGY, TOOLS, AND APPLICATIONS FOR REHABILITATION/TELEREHABILITATION

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ABSTRACT

A brief review of intelligent systems terminology is given with applications in tele- and local rehabilitation. This is followed by a description of extant intelligent systems software tools. A sample intelligent system (neurofuzzy muscle force estimator) for use in tele- and local rehabilitation is discussed.

MOTIVATION: HOW CAN INTELLIGENT SYSTEMS HELP REHAB?

While intelligent systems (ISs) apply to many fields, they are potentially quite powerful in tele- and local rehabilitation: they offer added value by incorporating professional (e.g., clinical) expertise into an evaluative or assistive system. They may also potentially adapt themselves to the needs or abilities of a specific user [1]. The need for better intelligent systems tools for healthcare applications was identified as one of the top societal priorities at the recent Workshop on Home Care Technologies for the 21st Century [2].

INTELLIGENT SYSTEMS: TERMINOLOGY & TOOLS

Intelligent Systems: modeling human cognition to add "smarts" to hardware & software.

ISs handle ambiguous or incomplete data (rather than random/probabilistic); they can adapt (learn). "Intelligence" refers to low-level, human-like cognition rather than conventional artificial intelligence's (AI) symbolic approach [3]. Fuzzy logic, neural networks, and probabilistic reasoning are common techniques for building intelligent systems [1-4].

Expert Systems: capturing the knowledge of a human expert for others to use.

Conventional AI mimics human intelligence symbolically in language forms and rules; a knowledge base is constructed to store the information [4]. An expert system seeks to represent "if-then" decision-making of a human expert, given a narrow enough problem area and reasonably explicit knowledge.

Fuzzy Systems: flexibility for handling expert knowledge with nonlinear/vague/ imprecise data.

Crisp logic only allows discrete yes-or-no membership in a given set; fuzzy logic allows elements to assume partial membership. Chapter 2 of [4] illustrates the power of this: consider "tall" people, where "tall" implies "height over 6 feet." In a classical set, "6 feet" denotes a crisp boundary: someone 6.001 feet tall is included, but someone 5.999 feet tall is not. Fuzzy logic gives both individuals partial membership—an intuitive approach to natural imprecision. Membership values in a fuzzy set may be discrete or continuous along the range [0 1].

Fuzzy systems employ fuzzy logic through inference: "if x is A, then y is B." Classical crisp inference is a subset of fuzzy inference. Consider this inference: "if a tomato is red, then it is ripe." The degree with which the tomato satisfies "redness" (its membership value along [0 1]) dictates its membership in the set "ripeness." Expert systems and control systems, such as for functional electrical stimulation [6], are frequently implemented as fuzzy systems.

Neural Networks: allowing "learning" with context of nonlinear/vague/imprecise data.

Artificial neural networks consist of processing elements ("artificial neurons") connected to each other in layers. Elements in a layer connect with elements in the same or other layers via weights. The weights are adjusted as the network learns; they thus act as the network's long-term memory. Learning can be supervised (the system adjusts its weights until a given input's output matches the desired output), unsupervised (the system adjusts its weights until it has organized itself), or reinforced (the system adjusts its weights based on feedback from an evaluative "critic"). Each method of learning has several well-established implementation algorithms.

Like classical optimization, neural nets feature a "plant" to optimize (e.g., the network itself); constraints; goals; and algorithms for reaching goals while obeying constraints. Like fuzzy systems, neural nets offer design flexibility and robustness to nonlinearity and imperfect data. Unlike fuzzy systems, neural nets can learn/adapt by changing internal weights. However, human expert knowledge is easily designed into a fuzzy system, yet this proves difficult for neural nets. Neural nets can be used to help other intelligent systems adapt/learn, but they are often used to implement models (e.g., muscle) themselves [7].

Neurofuzzy Systems: learning & expert knowledge in context of nonlinear/vague/imprecise data.

Neurofuzzy systems offer the best of both. The configuration can be fuzzy-neural (e.g., fuzzy neurons) or neural-fuzzy: one possibility would be a fuzzy expert (e.g., the muscle force estimator above) which uses a neural network to tune its membership parameters. Other examples include fuzzy inference systems implemented as neural nets, like FALCON [3] (the Fuzzy Adaptive Learning COntrol Network) and ANFIS [4] (the Adaptive Neuro Fuzzy Inference System).

Intelligent Systems Tools

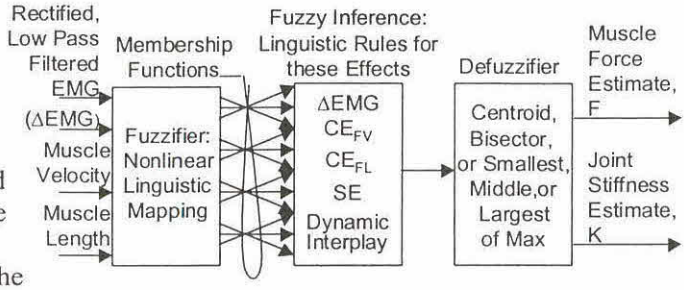
Many software packages are available to an IS designer: some, freely downloadable from the internet; others, commercially available. Some available packages:

- CLIPS (free): http://www.ghg.net/clips/CLIPS.html
- Jess (free): http://herzberg.ca.sandia.gov/jess/
- Fuzzy Jess (free): http://ai.iit.nrc.ca/IR_public/fuzzy/
- Fuzzy CLIPS (free): http://ai.iit.nrc.ca/fuzzy/fuzzy.html
- MATLAB (commercial): www.mathworks.com

NEUROFUZZY EXPERT APPLICATION—MUSCLE FORCE ESTIMATOR

A rehab clinician (e.g., physiotherapist) could benefit from an expert system which takes electromyogram (EMG) data and estimates muscle force and joint stiffness from rules capturing the properties of a nonlinear dynamic muscle model. This framework also allows inclusion of other clinically-oriented rules (e.g., to identify specific pathologies or rehabilitative progress).

To combine clinical expert knowledge with the Hill muscle model [5], a neurofuzzy expert muscle force estimator, which uses a neural net for tuning membership function parameters, is being developed (see Figure). The goal is to provide accurate estimates of muscle force and joint stiffness from velocity, length, EMG, and change in EMG by using the nonlinear physical properties of muscle neglected by other methods (e.g., smoothed, rectified EMG alone). The fuzzy muscle force estimator will be part of a clinician-assistant expert system that will take the force estimates and offer intelligent suggestions (e.g.,



"movement behavior is pathological"; "improvement is occurring"; or whether a certain assistive technology enhances performance).

MATLAB v. 5.2 is being used to develop this expert system. The fuzzy GUI sufficed for simple rules, but there was no access to the membership function parameters for neural net tuning. Thus, a more complete fuzzy inference engine is being developed to support critical neurofuzzy aspects of development; to allow more sophisticated/intuitive rule constructions (fewer rules through membership function combinations and hedges); and to allow complete control over the internal fuzzy mathematics (helpful, although MATLAB supports user-added membership functions and fuzzy operations). For cases MATLAB can handle, the new fuzzy inference engine has produced identical results. While currently coded in MATLAB for verification against MATLAB fuzzy GUI results, it is expected to be re-coded (e.g., in Java or C++) with its own GUI, and made available to other researchers as needed.

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A FINITE ELEMENT MODEL OF THE FOREFOOT REGION OF ANKLE-FOOT ORTHOSES FABRICATED WITH ADVANCED CARBON COMPOSITE MATERIALS

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ABSTRACT

This paper discusses the development of a finite element model (FEM) of the forefoot region of ankle-foot orthoses (AFOs), or rigid ankle braces, that are constructed of advanced composite materials. FEM can be used to help develop new AFO designs and determine their feasibility before clinical trials. FEM models of two different AFO forefoot region designs were modeled. The FEM models had mean errors below 20% for the load versus deflection properties. Also, the model predicted that one AFO design allowed 50% more deflection at the same load, which correlated with experimental results by 75 percent.

INTRODUCTION

There is a need for strong yet lightweight ankle-foot orthoses (AFOs), or ankle braces, to provide additional support and maintain stability during standing and ambulation. The conventional material used is polypropylene, a thermoplastic that can be easily molded to a positive mold of a patient's limb and easily postformed (1). However, for many AFO users, polypropylene AFOs are too bulky and heavy, and offer only limited rigidity in some planes during ambulation (2).

Researchers, including those at Rancho, have begun to explore using composite materials as an additional material for AFO construction (2,3) (Figure 1). At Rancho, a team has been studying the feasibility of AFOs using pre-impregnated (prepreg) advanced composite carbon, aramid and glass fibers (2), as seen in figure 1. Orthoses built of advanced composite materials- highly engineered materials designed initially for the aerospace industry-, show promise. The advanced composite AFOs have a higher strength-to-weight ratio than polypropylene AFOs, as a result of significantly different material properties. This has allowed researches and orthotists to fabricate novel AFO designs (2).

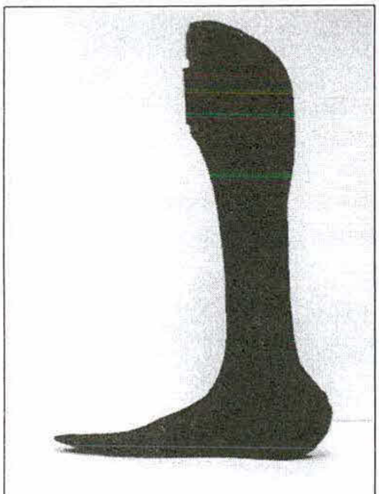

Figure 1: Full-Toe Carbon Composite AFO

Only recently has FEM been used to assess thermoplastic AFOs (4), perhaps due to challenges of modeling thermoplastic materials and a complex shape such as an AFO. FEM has not been used to model composite AFOs, which have an additional difficulty in the directional properties of the composite materials.

PURPOSE:

Recent advances in FEM software modeling programs have allowed the modeling of composites and laminates (which have a high length to thickness ratio) as a 2-D surface with laminate properties have. Using these new programs, an AFO can be modeled as a 2-D laminate shell instead of a 3-D solid. By addressing these limitations in order to improve the computer models, FEM may prove to be a useful tool in the design of orthotics, potentially reducing time and cost in the design and testing of new orthosis designs.

METHOD

The FEM model was generated on a PC using the MacNeal-Schwendler Corporation (Los Angeles, CA) MSC's Patran finite element analysis software package. The analysis of the FEM model was done on MSC's Nastran package. Both software packages were used on a Windows NT workstation. The models were built using only plain weave and braided prepreg fabric materials. The models were 2-D surface laminate models (5). For each surface, the appropriate materials, layers, and orientations of the carbon plain weave fabric and carbon braid fabric were assigned.

The plain weave and braid fabrics were modeled as 8 layers of laminates, at alternating orientations. Each laminate layer is 1/8th the original ply thickness for the material being modeled (plain weave fabric = 0.206 mm / fabric layer, braid fabric = 1.206 mm / fabric layer).

Two partial AFOs consisting of the forefoot region and side sections were manufactured to test the computer models created. After the AFOs were created, the dimensions of the AFO were measured to create the computer model. The dimensions were taken from a fabricated AFO, since it is difficult to create composite AFOs to precise dimensions due to the complex contours of the positive cast and custom lay-up procedure used to create each AFO. The FEM software was used to create a mesh on each surface, with each mesh element with an edge length of 4 mm (Figure 2).

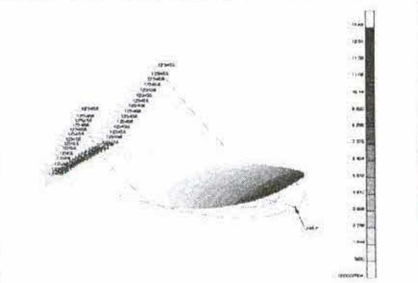

Figure 2: Deflected FEA model of forefoot region of an AFO.

After the AFOs were manufactured, they were tested in a stiffness jig, which applied a vertical load to the tip of the AFO at a 30^{0} orientation to the vertical axis. This simulates the load condition at the terminal stance of gait (6). The experimental results (load vs. deflection) were compared to the expected results from the FEM models.

RESULTS

The experimental testing showed that the model had an error less than 20% for all the loads applied (Tables 1 and 2).

Load	Model Deflection	Experimental Deflection	Error
58 N	5.45 mm	5.08 mm	7.3%
102 N	9.64 mm	9.78 mm	1.4%
146 N	13.83 mm	15.24 mm	9.3%
191 N	18.20 mm	21.84 mm	16.7%
236 N	22.21 mm	26.04 mm	14.7%

Table 1: Design #1 Results

Load	Model Deflection	Experimental Deflection	Error
58 N	8.38 mm	8.64 mm	3.0%
102 N	14.79 mm	17.91 mm	17.4%
146 N	21.21 mm	25.91 mm	18.1%

Table 2: Design #2 Results

DISCUSSION

This research attempted to create a working FEM model of the forefoot region of an AFO built with carbon composite materials. Two different AFO forefoot region designs were created for testing. Each design was modeled on the FEM software package using the mechanical properties calculated earlier in this study. The AFO forefoot region models had an error under 20% for the load/deflection response

The models also showed one advantage of using FEM in analyzing different AFO designs. The FEM models predicted that the second design would deflect 54% more than design #1 under the same load. This matched with the experimental results. This shows that the computer model was able to predict how changes in the geometry and lay-up can affect AFO performance. Knowing this, a small database could be established of several different designs. Then, as new designs are developed, they could be modeled and compared to this database to predict how they behave relative previously modeled designs in the database.

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APPLICATION OF A COMMERCIAL DATALOGGER FOR REHABILITATION RESEARCH

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ABSTRACT
To achieve validity in rehabilitation clinical research, data should optimally be collected while subjects are engaged in activity representative of daily living. This paper describes modifications made to a commercial, battery-powered datalogger so that the logger could be mounted on personal wheelchair and used to record the subject's propulsion activity at home. The resulting system has been sent home with one subject for a two week period and provided an accurate, unbiased log of this individual's daily wheelchair usage including time in motion, distance covered, and velocities. Data can be quickly transferred from the datalogger's memory chips to a desktop PC and be analyzed and graphed with MATLAB.

INTRODUCTION
When rehabilitation research takes place in a laboratory, subjects are aware that data is being collected and may perform in an atypical manner - not as they would if the same activity took place at home. This threat to research is referred to as the Hawthorne effect (1). For quantitative data collection, a portable, battery powered datalogger can sometimes be employed. This device travels with the subject and silently and independently records the desired data. Commercial one board dataloggers (2)are available that will operate for several weeks on a nine volt battery and can record up to 400,000 bytes of data on non-volatile memory chips. In an ongoing research project, the Human Engineering Research Laboratories successfully developed a weather-proof datalogger that unobtrusively attaches to manual and electric powered wheelchairs and records the subjects' movement activity. The client does not have to switch the datalogger on and off. The datalogger automatically "wakes up" whenever the chair is moved and automatically "hibernates" to conserve power whenever the chair is stationary.

METHODS
The goal of this particular research was to determine whether the power assist units on the Yamaha II manual wheelchair would encourage increased voluntary usage by consumers over their own traditional manual wheelchairs. An invisible, unobtrusive data logging system was required that would operate unattended for up to 14 days during a take-home trial.

The TFX-11 datalogger/controller is a single board computer with two processors; a Motorola 68HC11F1 and a PIC16C62. The PIC processor has extremely low current consumption and during testing operated up to nine days on a single lithium nine volt battery. The PIC processor will "wake up" the 68HC11F1 when data needs to be collected and stored. The system has 128 K of static

RAM for programs and 472 K of serial flash EEPROM for data storage. The system software includes a BASIC interpreter which allows fast program development.

Movement sensing components were developed that can be quickly mounted on a variety of subjects' wheelchairs. Three permanent magnets are attached with slotted machine screws and pinch nuts to three spokes equally distributed around the perimeter of one rear wheel. A reed switch is mounted on the wheelchair frame underneath the path of the magnets as depicted in Figure 1.

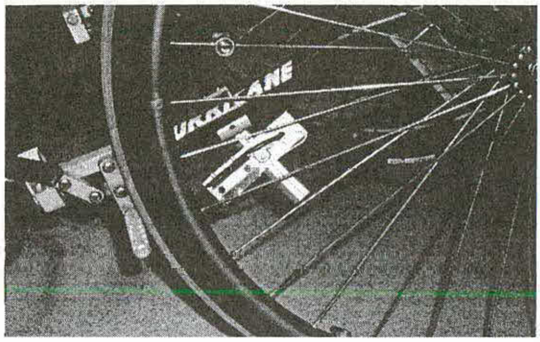

Figure 1. Magnet and reed switch sensor

A machined aluminum enclosure was created with Feature CAM (3) to protect the TFX 11 computer boards from weather and impact damage (Figure 2). The box utilizes an O ring seal and has a separate chamber to retain two nine volt batteries. Split ring clamps on the exterior of the box provide convenient, reliable mounting to a wheelchair frame tube.(Figure 3)

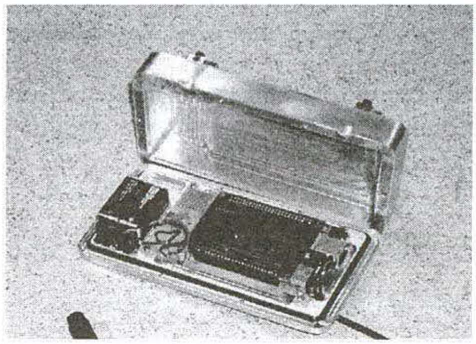

Figure 2. Machined aluminum enclosure

A shielded cable is used to convey the reed switch status to the digital I/O board of the TFX-11. An RC network was used as a low pass filter to exclude switch bounce and other signals over 10Hz. The authors felt that the nine pin DIN connector provided by Onset computer for parallel data transfers might fail with repeated cable insertions so it was replaced with a 10 pin modular jack.

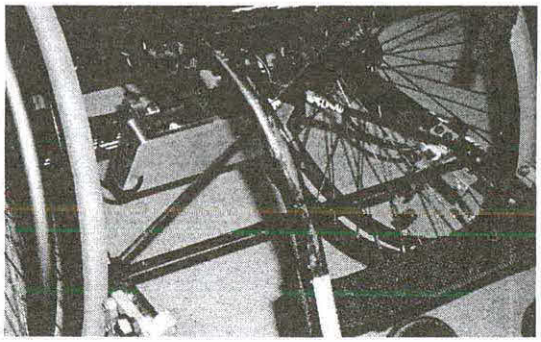

Figure 3. Enclosure installed on subject's wheelchair

The software program for data collection was written in BASIC. During periods of inactivity only the PIC microcontroller is active. When a magnet passes over the reed switch, a pulse is transmitted to digital input #1. The main processor is brought out of hibernation and a time stamp is recorded in non volatile memory. A timestamp consumes only four bytes so over 100,000 time stamps can be recorded.

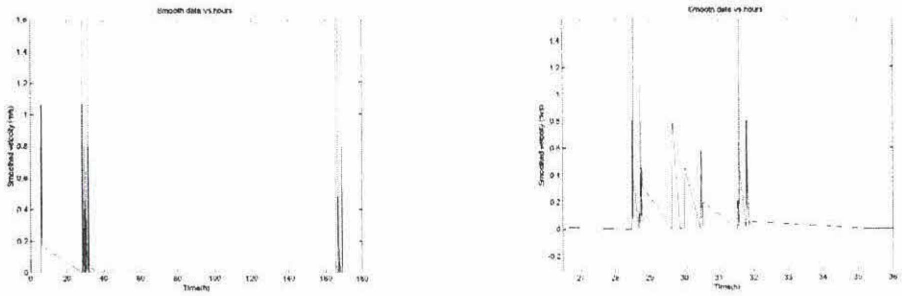

Figure 4. Velocity graphs generated by MATLAB (4)

RESULTS

Figure 4 illustrates some typical activity graphs that can be reduced from the time stamp files. The left graph covers activity over a one week (168 hours) period. The subject used her wheelchair on the second and seventh day. The graph on the right provides more detail on the sequence of movements that took place on the second day. Actual totals for this week were: Average velocity .85 m/s; Total distance 1350 meters; Total time in motion 7.64 hours

DISSCUSSION/CONCLUSION

Initial results indicate the Datalogger is reliable and accurate at slow chair speeds. One problem yet to be resolved is resolution. The current time stamps are only recorded to the nearest second. At higher wheelchair velocities, two magnets can pass over the reed switch in less than a second causing a pair of identical time stamp. The calculated velocity will suddenly drop to zero in the middle of a bout when this happens. The authors are smoothing the data in MATLAB to remove these errors. A better long term solution will be to change the recording software to include tenths of seconds.

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3. Feature CAM (CNC milling machine software) Engineering Geometry Systems 275 East South Temple, Suite 305, Salt Lake City, UT 84111

4. MATLAB (data reduction and graphing software) MathWorks, Inc., 24 Prime Park Way, Natick, MA 01760

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WHEELCHAIR SEATING AND POSITIONING OUTCOMES IN THE ELDERLY NURSING HOME POPUILATION

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ABSTRACT

The purpose of this study was to investigate whether or not the elderly who reside in nursing homes and sit in a wheelchair for 6 hours a day or longer, benefit from a custom fit wheelchair and seating system. Through an experimental design 24 people (60-98 years) were randomized into two groups (intervention & control), and they received a new wheelchair, cushion, and custom seat back. All were given four outcomes tests at specific time intervals. The administration of the Rand SF 36, QUEST, wheelchair mobility, and postural stability tests were performed to compare current systems with custom prescribed systems.

RESEARCH QUESTION

The objective of the study was to investigate the level of function and quality of life in elderly persons who use manual wheelchairs. Four hypotheses were established to enable us to measure independent mobility, satisfaction with assistive technology, posture, and quality of life. The hypotheses are that the intervention group:

1. *Will have less difficulty independently propelling their wheelchairs.*
2. *Will express greater satisfaction with their assistive devices.*
3. *Will exhibit greater postural stability.*
4. *Will report higher quality of life.*

METHODS

Groups: Subjects were randomly divided into two experimental groups, intervention and control. The intervention group received their new wheelchair three months before the control group. See table #1.

	Visit #1	Visit #2 (3 Months)	Visit #3 (3 Months)
Intervention	Old w/c	New w/c	New w/c
Control	Old w/c	Old w/c	New w/c

Table 1: Intervention & Control group time frame
* Intervention: Visit #2 is 3 months after receiving new wheelchair
* Control: Visit #3 is 3 months after receiving new wheelchair

Subjects: 34 people using an experimental design were selected from 3 different nursing home facilities. They gave written consent to participate in the study. 27 were female and 7 were male. The mean age of the participants was 82.4 ± 9.8 years. 10 subjects dropped out due to death, change of health status, etc. 24 of the subjects completed all phases of the study. Upon completion of the study there were 12 controls and 12 interventions.

Data Collection: Quebec User Evaluation of Satisfaction with Assistive Devices (QUEST) was interactively administered to all of the subjects at visit 1, 2 & 3 (1). The subjects rated (1-5 scale) different characteristics regarding "satisfaction" levels with their old and new wheelchair/seating intervention.

Rand SF-36 general health status questionnaire was interactively administered to all of the subjects at visit 1, 2 & 3 (2). The subjects responded to questions by sorting through the given list of possible answers and choosing the one that best describes they way they felt at that point in time.

Wheelchair Mobility: Subjects were asked to manually propel their wheelchairs. A method of testing was determined by professionals at the University of Pittsburgh for comparing w/c mobility differences between test phases. There were two separate tests, Test 1 and Test 2. Test 1 was a timed course on a level tile surface with the straight distance of 25 feet. Test 2 was a timed course on a level tile surface of 10 feet straight, 90-degree right turn, and then 15 feet straight for a total distance of 25 feet. The subjects performed Test 1 and Test 2 three times at each three-month interval.

Posture Stability: Subjects were asked to physically reach forward and lateral while situated in their wheelchairs. The method of testing was determined by professionals at the University of Pittsburgh and adapted from Axelson and Chesney (3). The subjects' most dominant arm was measured. Subjects had their feet placed on a telephone book. Every subject had their arms placed on their laps-not the arm rests. C-7 and the seat back were marked with tape so the subjects returned to neutral after each lateral reach. The restraining devices were taken off. After a detailed explanation and demonstration, the subjects performed the two reach tests (Fig. 1 & 2).

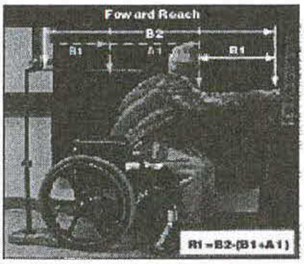

Fig. 1 (Forward Reach)

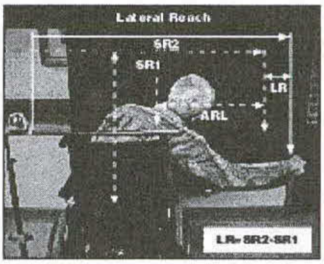

Fig. 2 (Lateral Reach)

RESULTS

The results for the four areas of testing were calculated and analyzed. The results of the four phases are in Tables 2-4.

DISCUSSION

Analysis of the differences between a current wheelchair and a custom prescribed wheelchair and seating system statistically and clinically show that an elderly wheelchair user will benefit from a custom prescription. The intervention groups did independently propel their wheelchairs easier than the control group. Overall the subjects in the custom fitted wheelchairs and seating systems became more mobile and generally more satisfied with their assistive technology (QUEST). The results that the subjects became faster in the new wheelchair are statistically significant ($p < 0.05$).

The two measures of postural stability do show differences in wheelchairs and seating systems. The subjects' forward reach did increase in the new intervention but the lateral reach appeared to decrease. The increase in forward reach is probably the result of feeling more secure because the new seating system is properly supporting the pelvis, thighs, and torso. The decrease in lateral reach can be attributed to subjects being prescribed contoured seat backs. Statistical analysis shows that the subjects who received a contoured seat back were more limited than those who received a planar seat back.

Analysis of the Rand SF-36 shows that the intervention group did report a higher quality of life than the control group in the area of role and social functioning. These results are also statistically significant ($p < 0.05$). Overall, all of the subjects benefited in some way or another from receiving a custom fit wheelchair and seating system.

As well as the statistical results reported there are a number of clinical observations that support our hypotheses. Both the subjects and caregivers were better educated as a result of this study. Subjects felt they were more knowledgeable with the decision of choosing assistive technology, and the quality of wheelchair and seating provisions increased in all 3 nursing homes over the two years of this project.

	Interv/Control	Visit #1 (Baseline Time)	Visit #2 (change)	Visit #3 (change)
Test #1(25ft)	Intervention	Old w/c 41.5 + 53.5	New w/c -4.3	New w/c -1.3
	Control	Old w/c 47.9 + 35.5	Old w/c 0.3	New w/c -16.8
Test #2 (10ft,rt turn, 15ft)	Intervention	Old w/c 51.4 + 53.4	New w/c -5.2	New w/c -4.0
	Control	Old w/c 69.4 + 60.9	Old w/c -2.8	New w/c -18.4

Table 2: Independently propelling wheelchairs for Test 1 & 2. A comparison of intervention vs. control groups.

	Visit #1 (Global Score)	Visit #2 (change)	Visit #3 (change)
Intervention	Old w/c 3.72	New w/c +0.93	New w/c +0
Control	Old w/c 3.14	Old w/c -0.42	New w/c +2

Table 3: QUEST: Rating global satisfaction. Comparing a change in satisfaction between the intervention & control groups regarding their new & old assistive technology (manual wheelchair). Scale is 1-5 (1= not satisfied at all, 5 very satisfied).

	Interv/Control	Visit #1 (Baseline)	Visit #2 (change)	Visit #3 (change)
Lateral Reach	Intervention	Old w/c 259 + 58.9	New w/c -22.0	New w/c -13.4
	Control	Old w/c 237 +68.7	Old w/c 9.8	New w/c -8.3
Forward Reach	Intervention	Old w/c 272 + 106	New w/c 18.8	New w/c 22.9
	Control	Old w/c 276 + 131	Old w/c -19.9	New w/c 39.5

Table 4: Posture: Postural Stability. Comparing forward & lateral reach lengths in the old & new wheelchairs between the intervention & control groups. Measurements were recorded in millimeters.

	Interv/Control	Visit #1 (baseline)	Visit #2 (change)	Visit #3 (change)
Role Functioning	Intervention	Old w/c 68.1	New w/c +20.0	New w/c -8.33
	Control	Old w/c 64.3	Old w/c -6.25	New w/c +11.4
Social Functioning	Intervention	Old w/c 81.9	New w/c +7.5	New w/c -9.38
	Control	Old w/c 80.4	Old w/c -18.8	New w/c +13.5

Table 5: Rand SF-36: Quality of life. Comparing role & social functioning in the old & new wheelchairs between the intervention and control groups.

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IS AN ITEM GOOD OR BAD? SELECTING THE BEST SUBSET OF ITEMS FROM THE ORIGINAL VERSION OF THE QUEST

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ABSTRACT

The Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) is an outcome assessment tool designed to measure satisfaction with assistive technology in a structured and standardized way. The purpose of this paper is to present the result of an analysis of the 24 items comprising QUEST and to explain how a subset of 12 items demonstrating optimal measurement performance was selected. The construction of tests with minimal length that yield reliable and valid scores is an important issue in the assessment of outcomes.

BACKGROUND

Etymologically, the word 'satisfy' means make enough. In appearance, the concept of satisfaction seems quite simple and easy to understand. However, from a theoretical point of view, it is rather complex. Although it is approached as a multidimensional concept, there is to date little agreement about the factor structure of satisfaction measures. Satisfaction is also an arbitrary concept that can mean different things to different people. Based on literature reviews of empirical satisfaction studies and theoretical frameworks (1), satisfaction as defined in QUEST refers to a person's critical evaluation of specific characteristics of the assistive technology device. Individual expectations, perceptions, attitudes and personal values affect this assessment.

In 1997, the RESNA Conference was held under the theme 'Let's Tango-Partnering People and Technology'. The subject of one presentation was the construction and the development of the original QUEST (2). The main features of this instrument assessment were as follows. Firstly, it was comprised of the 24 items (listed in Table 1). Secondly, it was created in a 'card-playing' format and the assessment materials were presented as a kit. This way, people unable to write or see clearly were not excluded from participating to the evaluation. Thirdly, the items were rated twice by the users. Using a specific classifying task, the user was firstly asked to rate the degree of importance he or she would attribute to the individual items. By doing so, individual potential differences were accounted for in the definition of the satisfaction concept. After that, there was another interactive task during which the user was asked to rate his or her satisfaction with all of the variables.

Since then several studies were conducted to assess the measurement properties of the original QUEST, both at the item and at the test level (1). It was necessary to act upon the obtained results and improve the tool.

OBJECTIVE

In test construction, an ultimate goal is to develop a test of minimal length that will yield scores with the desired degree of reliability and validity for the intended uses. Typically, this is accomplished by field selecting a large pool of items and selecting a subset of items from the pool that makes the greatest contribution in regard to precise indicators. The objectives of this study were to examine if there is a subset of items comprised in the QUEST that demonstrate optimal validity and reliability and to assess the factorial structure of the satisfaction concept being measured.

METHOD

Six measurement properties were identified as highly relevant for the item analysis. These included: (i) general acceptability; (ii) content validity, reflecting the importance to device users and to professionals; (iii) criterion validity, based on correlation with global satisfaction; (iv) contribution to internal consistency; (v) test-retest stability; (vi) sensitivity, with respect to the amount of variability in scores. Factorial analyses were performed to refine the item selection and explain how items tend to cluster together in a meaningful way with respect to the satisfaction concept. Principal Axis Factoring (PAF) is the most widely used method of factor extraction for explaining common variance and it was used in this study.

Data from three sources were used in the item selection process: a Montreal sample (n=158), a Dutch sample (n=253) and data derived from a previous International Content Validation Study (3).

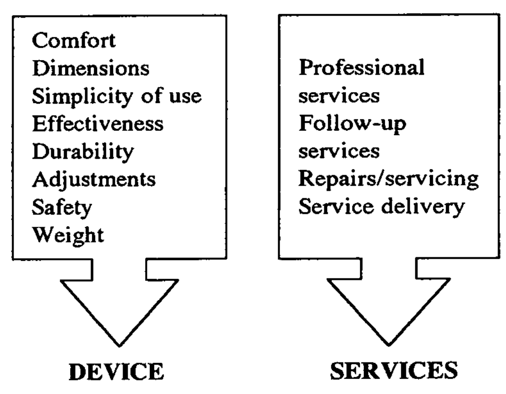
RESULTS

The 24 items comprised in the original version of the QUEST did not perform equally well against the six measurement properties. Some items (n=11) clustered in the upper part of Table 1 consistently showed desirable measurement properties. It was quite obvious that they were to be kept within the evaluation. On the opposite, another group of items (n=10) consistently has less than desirable measurement properties. It only made sense to remove them from the evaluation. For the few remaining items (n=3), inclusion or exclusion was decided by examining the internal consistency and the factorial composition of the whole scale. The best subset is comprised of 12 items.

Table 1: Items Performance with Respect to Measurement Properties

Good ratings	Comfort Dimensions Professional services Follow-up services Simplicity of use Adjustments	Safety Service delivery Effectiveness Repairs/servicing Durability
Both good and bad ratings	Weight Multi-purposefulness Transportation	
Bad ratings	Maintenance Training Device compatibility Appearance Installation	Cost Effort Motivation Reaction of others Social circle support

Figure 1: QUEST Factorial Composition



The results of the factorial analysis revealed that the underlying structure of satisfaction with assistive technology consists of two dimensions. As shown in Figure 1, the first dimension is related to the DEVICE and comprises eight items. The second dimension is associated with the SERVICES and includes four items. This solution accounted for 39.3% of the common item variance and for 48.4% of the total items variance (based on Principal Components Analysis). The main advantage of having the items grouped this way is the ability to get an aggregated score within each dimension and to increase the usefulness of the data obtained from the device users.

With respect to internal consistency, the Cronbach's alpha coefficient reached 0.82 (entire set of items), 0.80 (Device subscale) and 0.76 (Services subscale).

DISCUSSION

In the development of the QUEST, close examination of the item content was considered a logical and necessary step to establish the validity and the reliability of the scale. The methodology used examined items performance on six measurement properties, which is more than generally employed in item analysis. Moreover, the selection of items was optimized by submitting potentially suitable subsets of items to factor analysis. By applying this dual approach, it is hoped that the selection of the best set of the QUEST items was more robust then would normally be the case.

A meaningful and essential question to raise about a measure is whether it is consistent with the definition of the construct it is intended to be measuring. Factor analysis is one of the most powerful analytical approaches that can be used for this purpose. The results of this study suggest that satisfaction with assistive technology is comprised of two unobserved latent dimensions, respectively named assistive technology DEVICE and SERVICES. From a theoretical perspective, the emergence of the DEVICE factor supports the viewpoint that technology quality is a top priority in device selection, use and evaluation. The variables related to the SERVICES factor are of paramount importance and reflect the environmental influence and the service delivery impact on user perception.

Personality-based items such as *motivation* and *social circle support*, among others, did not perform well in the item analysis. Such results do not suggest that socio-cultural and motivational issues are not relevant, since very convincing evidence of their importance has been found in the literature (1). What this study's findings do suggest, however, is that other suitable instruments need to be developed specifically to address these aspects of consumer evaluation of assistive technology.

A remaining challenge is posed by the sensitivity of the 12-item version of the QUEST. In the present study, this measurement property was not confirmed for the aggregated 12 items nor for the subscales. It is hoped that future studies will show that the tool can discriminate among individuals with different satisfaction levels, over a large spectrum of disabilities and assistive devices.

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RELATIONSHIP OF PAIN PERCEPTION TO QUALITY OF LIFE IN A SPINAL CORD INJURY POPULATION

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ABSTRACT

It is well documented that people with spinal cord injuries (SCI) experience pain. It is of interest to know how self-perceived pain relates to other factors in one's life. To examine this relationship we asked subjects with SCI to complete several questionnaires and undergo a physical exam of the shoulder. The McGill Pain Questionnaire determined self-perceived pain. Results showed significant correlations between increased self-perceived pain and more difficulty in functional status specifically completing basic and intermediate activities of daily living.

BACKGROUND

It is well documented that people with spinal cord injuries (SCI) experience pain, with percentages that range from 14 to 94% [1]. Research has focused not only on the clinical manifestations of pain but also on how pain impacts psychosocial factors for the SCI individual. Pain has been defined as both neuropathologic pain and muscular pain. Results have varied depending on the measurement instruments used to determine pain, what psychosocial variables were examined and the type of statistical analysis completed.

It is of interest to know how self-perception of pain affects other aspects of one's life. This study examined self-reported pain and compared these results to pain diagnosed from physical exam as well as aspects of health status including functional status, depression, life satisfaction and interference of spinal cord injury.

METHODS

Thirty-nine subjects were recruited through inpatient records at a large SCI rehabilitation center and through mailings through vendors. Inclusion criteria for the study included having a traumatic SCI at the 4th thoracic level or below occurring greater than one year prior to the start of the study, using a manual wheelchair full-time for mobility and being able to provide informed consent.

All subjects were asked to complete a questionnaire packet and undergo a physical examination of the shoulder. The McGill Pain Questionnaire (MPQ) determined the score for self-perceived pain. The MPQ provides 15 descriptors and asks the subject to rate their pain on a 0 (indicating no pain) to 3 (indicating severe pain). By summation of the descriptors, a total score is provided as well as scores for sensory and affective pain dimensions. Other questionnaires that were completed to determine health status included the Functional Status Questionnaire (FSQ) (consisting of 5 parts), SCI-Interference Index, Center for Epidemiologic Studies Depression Scale (CES-D), and Life Satisfaction Index-A (LIS-A). [1-5] Standard scoring techniques for each of the questionnaires was used. Additional information was also collected on age, gender, years of spinal cord injury and body mass index (BMI).

Scoring for pain during the physical exam of the shoulder was scored on a 0-2 level on five different areas (shoulder internal and external rotation, abduction, and palpation of the biceps tendon and subdeltoid bursae) with zero indicating no findings and two indicating a clear-cut positive exam. The exam was completed on the right and left sides for each subject. Scores were summed across the five areas for a total pain score per side. After determining that the sides were highly related ($p < 0.001$), a total physical exam pain score was created by taking an average score between the right and left sides. The physician completing the exams was blinded to the scores of the MPQ.

Spearman correlations were completed between the outcome (Mcgill Pain Questionnaire-MPQ), pain score from the physical exam and the independent variables of LIS-A, CESD, SCI-Interference and FSI.

RESULTS

The 39 manual wheelchair users had a mean age of 35 $\pm$ 9.3 years and 69% were male. Mean years post spinal cord injury was 11.5 $\pm$ 5.9 years. Twenty-five of the 39 (64%) had SCI injury between T4-T9 with 36% at an injury level of T10 or below. Mean McGill Pain Score for the participants was 5.4$\pm$4.9 and 32% stated that they had 'discomforting' or 'distressing' pain at the time of the interview.

Correlations between the MPQ, physical exam and independent factors are shown in Table 1. There were no significant relationships between age, years of spinal cord injury, level of injury or BMI and self-reported pain.

Table 1
Correlation coefficients between McGill Pain Score and Independent Factors

MPQ	PE	LISA	CESD	SCI-Interference	FSI					
					Basic	Inter	PF	WP	SA	QOI
p-value	**0.001**	0.12	0.38	0.08	**0.05**	**0.002**	0.57	0.24	0.23	0.96
r	0.51	-0.25	0.14	0.28	-0.30	-0.46	-0.09	-0.23	-0.19	0.01

Basic- Ability to perform basic activities of daily living
Inter- Ability to perform intermediate activities of daily living
PF – Physiological Function
WP – Work Performance
SA – Social Activities
QOI – Quality of Interaction

Self-reported pain was highly related (p-value<0.001) to the physical exam, showing that the MPQ was representative of physician-assessed pain. Self-perceived pain was not significantly associated with life satisfaction, depression, or spinal cord interference. Higher pain scores were seen with lower scores (indicating more difficulty in completing the task) for the basic and intermediate activities of daily living reported in the FSI. Similar correlations were seen between the independent factors and the MPQ sensory pain dimension, with significant relationships seen between the basic and intermediate activities of daily living and MPQ-sensory. Conversely, when examining the MPQ-affect pain dimension, significant correlations were seen with physiological function and life satisfaction.

DISCUSSION

This study examined self-perceived pain in relation to other aspects of one's life. Self-perceived pain was determined not only by self-report but also by a physical exam. Results from our study suggest that self-perceived pain affects only activities of daily living, and does not affect emotional factors (i.e. depression), satisfaction with life, or interaction with society. This is partly in contrast to other research that shows increased pain is associated with decreased quality of life, specifically depression (6,7). Difference in results between studies is possibly due to the type of pain being analyzed. In our study, the relationship between the pain score and physical exam would tend to suggest that musculoskeletal injury was responsible for much of the pain opposed to other studies in which the pain is neuropathic in nature.

A limitation of this study is the cross-sectional design. It is unknown how the activities of daily living will further affect other psychosocial factors over time. It is possible that activities of daily living are the first factors that will suffer with the onset of pain. This could result in less community integration, resulting in depression and dissatisfaction with life. Future studies should follow individuals with SCI and determine the long-term affect that pain can have on quality of life.

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FUNCTIONAL STATUS AND WELL-BEING FOLLOWING TOTAL HIP REPLACEMENT REHABILITATION AS MEASURED USING THE SF-36

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ABSTRACT

Total hip replacement surgery is a common surgical procedure in the United States elderly population. Resulting functional status and well-being of elderly arthritis patients who have undergone such surgery may provide information that can be used to identify areas of function which may require additional physical or occupational therapy. The SF-36 was administered postoperatively at 4 months in elderly individuals with total hip replacement (THR) to assess health-related quality of life. This paper reports on the results available to date and contrasts the mean SF-36 scores for this study group to that of two previously published studies involving elderly total hip replacement populations, and to that of the general population. Results indicate that data from this study compares to previously published study results. Studies using older participants had lower SF-36 scores when compared to studies using younger participants.

BACKGROUND

Over 124,000 total hip replacement (THR) surgeries are performed annually in the United States in an effort to increase mobility and comfort in those having arthritic, deteriorating or injured hips.[1] It is postulated that THR patients exhibit increased levels of bodily pain and muscle fatigue causing limitations in physical functioning, and placing them at higher risk for falls, joint dislocations, decreased mobility and other injuries while performing activities of daily living. For the elderly population, loss of independence in performing activities of daily living may require hiring/paying costly personal assistance, or transferring to an assisted living environment. This analysis is part of a pilot study examining the relationship between muscle activity and fatigue, and performance of activities of daily living in an elderly THR population.

A two-year, randomized controlled study conducted by Munin[2] examined the effect of early inpatient rehabilitation on 86 elderly patients (mean age = 74) undergoing elective hip and knee arthroplasty. All patients were identified as high risk for inpatient rehabilitation based on age and/or comorbid conditions. Health status using the RAND 36-item health survey and functional performance was evaluated 1 month preoperatively, and postoperatively at 4 months. Munin found that patients in his study tolerated early intensive rehabilitation therapy, resulting in faster attainment of short-term functional milestones and reduced healthcare. In another study by Shields,[3] the relationship between the Quality of Well Being index (QWB) and SF-36 was examined in forty-three patients (mean age = 58) receiving total hip or knee replacement due to primary osteoarthritis. Shields measured health status preoperatively and postoperatively at 3 and 6 months and concluded that both survey instruments responded similarly, and that changes in health status scores over time were dependent on time elapsed since surgery.

In this paper, results from total hip replacement subjects from Munin's RAND 36-item survey and Shield's SF-36 scores (3 month results), are compared to SF-36 results obtained under this study. Data is also contrasted to control scores and that of the general population. The RAND 36-item survey is widely recognized as an equivalent instrument to the SF-36, with results from both surveys being highly correlated.[4]

METHODS

Subjects

This pilot study has been conducted as a case/control study. Ten case and ten control subjects are being sought for a total sample size of twenty subjects. This report provides preliminary findings collected from 8 subjects: 4 case and 4 control. Subject recruitment has been limited to the following inclusion criteria: a) 60-75 years of age ($\pm$ 3 yrs), b) osteoarthritis or rheumatoid arthritis (cases), no hip arthritis or discrete hip pathology (controls), c) no history of cardiovascular disease, excluding hypertension, d) no active corticosteroids, e) no surgical complications, and f) no ambulatory assist devices at time of study participation. Primary disease classification for case subjects to-date is osteoarthritis.

Case subjects were identified and recruited through the University of Pittsburgh Medical Center (UPMC) Orthopaedic Surgery department and UPMC Rehabilitation Hospital. Controls were recruited through association with case subjects, or University of Pittsburgh staff. Selected subject demographics are presented in Table 1.

Table 1: Selected Subject Demographics

Variable	Case Subjects (n=4)		Control Subjects (n=4)	
	Mean	SD	Mean	SD
Age (Years)	70.25	11.25	63	4.79
Osteoarthritis – years since diagnosis	11.25	12.7	--	--
% Female	50		100	

Instrument

General health status was obtained using the Medical Outcome Study SF-36. The SF-36 is a self-administered generic health assessment tool consisting of 36 items. Health concepts are measured according to the following scales: physical function (PH-includes lifting, bending, walking moderate distances), role limitation due to physical health (RP-time spent in work or regular activities, difficulty in performing activities), bodily pain (BP), general health (GH) social function (SF), vitality (VT), role limitation based on emotional health (RE), and mental health (MH). Scoring for each of the eight concepts of the SF-36 is on a 0-100 scale, with 0 indicating poor health. Scoring algorithms published by Ware[5] were used to calculate the scores.

Data Analysis

Given the current limited sample size of this pilot study, descriptive statistics were used to compare results of pilot data to those obtained by Munin and Shields, and to that of controls and the general population. Mean, standard deviation and range data were compared among the three studies, and mean data was contrasted to that of the general population. General population data was estimated from responses to the National Survey of Functional Health Status (NSFHS) cross-sectional survey conducted in 1990.[5] These results are widely used for comparative analysis.[5,6]

Procedure

The SF-36 was completed postoperatively at 4 months. Subjects were asked to respond to questions based on the previous 4 week time period.

RESULTS

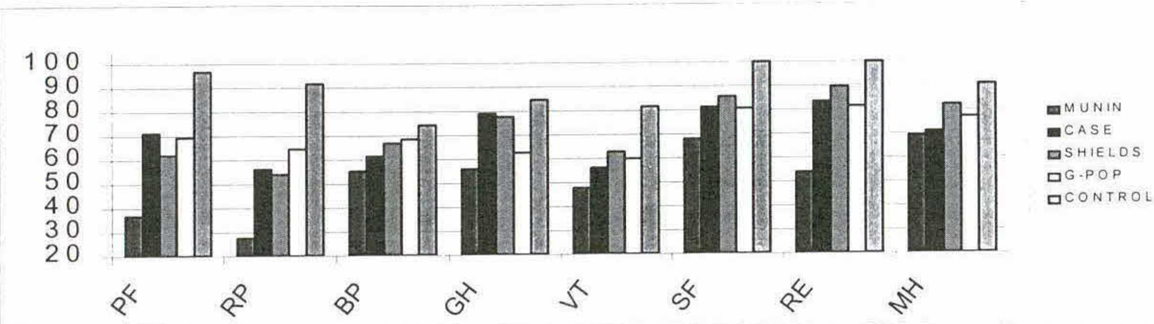
Contrasted to Munin's results (mean age: 74, $\pm$6.6 yrs), case subjects in the pilot study (mean age: 63, $\pm$4.8 yrs) reported higher mean scores for each of the eight health concepts, indicating better health states in each category. The greatest differences were noted for PF, RP and RE. Mean scores for Munin were 36.8 for PF, 27.5 for RP, and 54.0 for RE; compared to mean scores from this pilot study of 71.3 for PF, 56.3 for RP, and 83.3 for RE (Fig. 1).

Contrasted to Shield's results (mean age: 58, $\pm$14.3 yrs), case subjects in the pilot study had higher scores and reported less limitation in PF, somewhat less limitation in RP, and slightly higher

GH scores. In all other health status categories, case subjects reported lower or slightly lower results, indicating more or slightly more BP, less VT, and lower RE and ME scores.

Contrasted to control scores, all controls reported higher scores on the SF-36 than did case subjects, with a significant difference ($p<0.05$) for PF, and trending towards significance for MH. Contrasted to the general population (aged 65-74 yrs), case subjects reported greater limitations in PF, experienced more BP, and reported lower VT and MH scores.

Figure 1: Mean Scores of Health Status Survey Results



PF=Physical Functioning, RP=Role Physical, BP=Bodily Pain, GH=General Health, VT=Vitality, SF=Social Functioning, RE=Role Emotional, MH=Mental Health

DISCUSSION

Results indicate that data from this study compares to previously published study results. Studies using older participants had lower SF-36 scores when compared to studies using younger participants. It is suggested that additional studies be undertaken to examine whether or not age and comorbidity factors play an important role in recovery after total hip replacement surgery.

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USER-CAREGIVER AGREEMENT ON PERCEIVED PSYCHOSOCIAL IMPACT OF ASSISTIVE DEVICES

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ABSTRACT

Assistive technology specialists often explore psychosocial issues with both a device user and his/her primary caregiver, or the primary caregiver alone in instances where the user cannot communicate his/her concerns. In this study, psychosocial impact measurements were taken from 23 matched pairs of device users and their primary caregivers. Devices used included electronic aids to daily living, voice-output communicators, walkers, wheelchairs, and writing aids. The measurement tool was the Psychosocial Impact of Assistive Devices Scale (PIADS). There were significant positive correlations between users and caregivers on 2 of the 3 PIADS subscales (Competence and Adaptability), indicating substantial agreement on the degree of perceived psychosocial benefit from using the devices. The results have important implications for improving the prescription of assistive devices, to include perspectives from both users and their caregivers. They are helpful also in furthering research on the use of the PIADS by caregivers, to provide proxy measures of perceived psychosocial benefit.,

BACKGROUND

Psychosocial factors are known to play a significant role in determining the outcomes following the prescription of an assistive device (1). Individuals who perceive that they get little or no benefit from a device are more likely to abandon, misuse or reject it than those who believe the device improves some aspect of their quality of life. (2-5).

Assistive technology specialists often explore psychosocial issues with both a device user and his/her primary caregiver, or the primary caregiver alone in instances where the user cannot communicate his/her concerns. As a result of brain injury or degenerative neuromuscular disease, many device users rely on their caregivers to facilitate their communications or speak on their behalf. In recent years, tools have become available to reliably measure user perceptions of the impact of assistive devices (6, 7), but they have not been used systematically to examine the level of agreement between user and caregiver. If users and their caregivers disagree substantially about perceived benefits, there could be serious implications, especially if these couples need to have a shared perception to help assure successful outcomes following device prescription. This research would also help determine whether currently available assessment tools might be used reliably by caregivers to give proxy reports of device impact on users.

RESEARCH QUESTIONS

The aim of this study was to examine the agreement between assistive device users and their caregivers on the user's perception of psychosocial impact relating to use of a device. A secondary goal was to examine the implications of the research findings for proxy ratings by caregivers of device impact on the user. This preliminary report presents results from a sufficiently large sample from our study to give statistically reliable impressions. By the time the study has concluded, we hope to have at least doubled the sample size.

METHOD

Psychosocial impact measurements were taken from 23 matched pairs of adult device users and their primary caregivers. The users were 13 female and 10 male clients of the Assistive Technology

Clinic at Sunnybrook & Women's College Health Sciences Centre in Toronto. They all had a diagnosis of amyotrophic lateral sclerosis (ALS) except for one individual who had spina bifida. Devices used were electronic aids to daily living (n=2), voice-output communicators (n=4), walkers (n=2), wheelchairs (n=9), and writing aids (n=6). The relationship of the primary caregiver to the user took the following forms: spouse (n=19); son/daughter (n=2); parent (n=1); sibling (n=1).

The measurement tool was the Psychosocial Impact of Assistive Devices Scale (PIADS). The PIADS (6) is a 26-item, self-rating questionnaire designed to measure user perceptions of how assistive devices affect quality of life. It is intended to be a generic measure, applicable to virtually all forms of AT. The PIADS describes user perceptions along 3 dimensions: Adaptability (the enabling and liberating effects of a device); Competence (the impacts of a device on function, performance and productivity); Self-esteem (the extent to which a device has affected self-confidence, self-esteem and emotional well being). The PIADS is a sensitive measure of the impacts of a wide range of ATs, in populations of adults who have various forms of disability and medical condition (8).

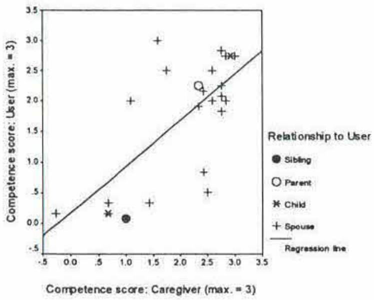
In our research project at Sunnybrook, user-caregiver couples are asked to complete the PIADS for each prescribed device at the time of each clinic visit or telephone follow-up. Caregivers are asked to use the PIADS to indicate how they thought the device had affected the user. Assessments begin 3 months after the user first receives the device, and at 3-month intervals thereafter. Users and their caregivers give independent ratings either in person, during a clinic visit, or by telephone interview with a research assistant. In this paper, we report the results for the first set of user-caregiver pairs for whom we have obtained completed PIADS scores from their earliest assessment.

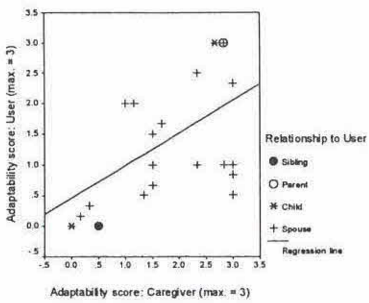
RESULTS

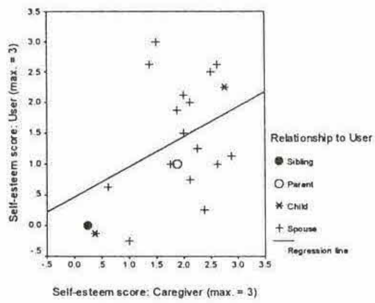
The following table shows the Pearson correlation coefficients and statistical significance for user-caregiver agreement on each of the 3 PIADS subscales. Note that the sample size relating to the result for the Self-esteem scale was 22, not 23. From one of the user-caregiver pairs, there was no response to one of the PIADS items pertaining to this subscale, and so this pair was omitted from the analysis.

	Competence	Adaptability	Self-esteem
Pearson correlation	.683	.536	.366
Significance (2-tailed)	.000	.008	.094
Sample size	23	23	22

The next 3 figures are bivariate plots of paired user-caregiver scores on each subscale, with regression line (i.e., line of best fit through the points).







There were significant positive correlations between users and caregivers on 2 of the 3 PIADS subscales, and they indicate substantial agreement on the degree of perceived psychosocial benefit from using the devices. Shared perceptions were much more likely for the Competence (the impacts of a device on function, performance and productivity) and Adaptability (the enabling and liberating effects of a device) subscales than the Self-esteem (the extent to which a device has affected self-confidence, self-esteem and emotional well being) subscale.

DISCUSSION

User-caregiver agreement on perceived psychosocial impact of assistive devices appears to be strongest in relation to functional competence and performance (i.e., how well the device helps the user to do the things they want and need to do). Caregivers seem to be far less adept at estimating a device's impact on the user's self-esteem, self-image and emotional state. Instances where users and caregivers disagreed on whether a device had a positive or negative impact were very rare. The results have important implications for improving the prescription of assistive devices, to include perspectives from both users and their caregivers. They are helpful also in furthering research on the use of the PIADS by caregivers, to provide proxy measures of perceived psychosocial benefit.

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TIMING FUNCTIONAL OUTCOMES USING A PERSONAL COMPUTER

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ABSTRACT
This paper considers the validity of a computer-based technique for timing functional tasks. Thirty-five healthy young adults walked 5 times along a 10m walkway while being videotaped from the side. One of these walks was normal, and the others were four gait patterns commonly used with assistive devices. Measurements were made from the videorecording using the computer-based technique and a multimemory stopwatch. The data from the two timing methods showed high degrees of correlation, indicating the validity of the new technique. This new technique could be applied to functional tasks other than gait. The computer removes the need for manual calculation, often a source of clerical errors, making the technique potentially more acceptable in clinical practice.

BACKGROUND

Perhaps one of the simplest indicators of functional ability is how quickly one can complete a task. This method of determining outcome is completely objective and has the added advantage of using a ratio level of measurement. The concept of timing has been applied to measuring functional tasks in rehabilitation. For example, walking speed has been cited as a particularly useful measure of functional mobility in stroke patients. (1) Wade (2) has made the point that therapists tend not to use timing of activities because it is felt that the quality of the movement involved in the task is more important. He goes on, however, to suggest that speed may be closely related to quality and states that "*...The 10m timed walk is remarkably simple, reliable, valid, sensitive, communicable, useful and relevant - almost the perfect measure!*" The measurement of walking speed requires only a timing device, such as a stopwatch, and a known distance. The stopwatch may also be used to determine stride times if it has a multimemory capability. (3) The drawback of using a stopwatch for these measurements is that the data have to be recorded manually and results, such as walking speed and mean stride time, calculated. Using a personal computer as the timing device, with input via the mouse button, these problems would be overcome. Since time could be used as an outcome measure for many functional activities, it was decided to implement a computer based technique for measuring time intervals and determine the validity of the technique for measuring a functional task. This paper describes the results obtained using this new technique when compared to stopwatch data collected on the temporal gait parameters.

RESEARCH QUESTION

Is a computer-based technique as valid as a multimemory stopwatch when used to measure walking speed and stride time?

METHOD

This project was conducted during a scheduled laboratory practical session in which 35 students in the first year of the professional component of the physical therapy curriculum walked under each of the following conditions: swing-to gait using crutches and non-weightbearing on the left foot, four point gait with crutches, two point gait with crutches, modified two point gait with one crutch on the right side and a normal gait at self-selected medium speed. Under each of these conditions the subject walked along a 10m walkway while being videotaped from the side. Optical switches were used to provide an audible signal of when the subject entered and left the central six meters of the walkway. Two techniques were used to collect the data: a multimemory stopwatch and a computer. One investigator analyzed all 175 walks from the videorecordings using both the multimemory stopwatch and the computer techniques. Using the stopwatch, walk time was determined by pressing the start/stop button as the subject entered and left the central 6m of the walkway. To determine stride duration, the lap or split button was clicked at the instant of every right heel contact within the central 6m. The intervals or laps are stride times, with the exception of the first and last which are incomplete strides. The computer-based technique utilized the mouse as the input device. The mouse button was clicked as the subject entered the central 6m of the walkway, on every right heel contact within the central 6m and as the subject left the central 6m. Both techniques yielded the time taken to walk 6m (walk time) as well as the stride times. From these data were calculated walking speed, mean stride time and mean stride length, the latter being the product of walking speed and mean stride time.

RESULTS

The walk time, walking speed, stride time and stride length data collected using the stopwatch were plotted against those obtained using the computer technique. A simple regression analysis was done on each graph which yielded the equation for each regression line as well as the coefficients of determination (R^2) which indicate the percentage of variance that is shared by the two variables. This analysis produced the following equations:

Walk Time (s)	$y = 0.068 + 0.997x$	$R^2 = 0.998$
Stride Time (s)	$y = 0 + 0.992x$	$R^2 = 0.998$
Walking Speed (m/s)	$y = 0.018 + 0.968x$	$R^2 = 0.992$
Stride Length (m)	$y = 0.051 + 0.940x$	$R^2 = 0.969$

The two techniques produce data with very high correlations with the coefficients of determination being close to the perfect value of 1.00. The equations represent a straight line of the form $y = c + mx$, where y is the value on the ordinate (computer measurements), x is the value on the absisca (stopwatch measurements), c is the intercept on the ordinate and m is the slope. If the data collected by the two techniques were identical then the equations would be $y = x$, i.e. the intercept would be at zero and the slope would equal 1. It can be seen for all the comparisons, the intercepts are very close to zero and the slope (m) values are similarly close to 1.

A useful method of determining how close the data from the two measurement techniques are is to calculate the difference between them. One can then determine the mean difference and the ninety five percent confidence interval (t 95%). Ideally the mean difference should be zero with a very small t 95%, reflecting very little difference between the two sets of data and a high degree of confidence in either data set. The results of this analysis are shown below

Walk Time (s)	diff = - 0.03	t 95% = 0.030
Stride Time (s)	diff = - 0.01	t 95% = 0.004
Walking Speed (m/s)	diff = - 0.01	t 95% = 0.005
Stride Length (m)	diff = - 0.02	t 95% = 0.010

The mean values for the differences between the two techniques are close to zero for all the parameters measured, the maximum mean difference being - 0.03s for the walk time. Likewise the values for the confidence intervals are small for each of the parameters.

DISCUSSION

The actual measurements of walk time and stride time were very close for the two techniques. The difference was - 0.03s for the walk time data and - 0.01s for stride time. To put this into perspective, the range of walk times was 3.5s to 24.17s, while stride times varied from 0.92s to 3.43s. So for both measurements, the error was at worst approximately 1%.

Walking speed and stride length, which were calculated from the measured values of walk times and stride times, showed more variability. It was noticed that the data at the higher walking speeds and longer stride lengths showed the greatest degree of variability. The explanation for this lies in the inherent error in clicking the stopwatch or mouse button at a specific instant. This error is going to be more significant when the time intervals to be measured are short. The faster one walks the shorter the time it will take to cover the set distance. Consequently, when walking speeds are calculated the variability will become more evident as speed increases.

As walking speed increases stride length increases resulting in fewer strides that could be timed in the 6m distance used. The fewer the number of strides the more noticeable will become the timing errors. Also, at faster walking speeds stride times will be shorter, again adding to the error. Stride length was calculated as the product of walking speed and stride time and since the error in both of these increases with walking speed, the variability of the longer stride lengths used in faster walking will be more marked. From a clinical standpoint this may not be a problem given that most patients tend to walk slowly. The results indicate that both the stopwatch and computer-based techniques produce comparable data. The new technique removes the need for manual calculation of data making it potentially more acceptable for clinical use, not just for assessing gait but for providing outcome measures for many other functional tasks of interest to clinicians involved in rehabilitation.

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BEHAVIOR FREQUENCY DATA SITE FOR REHAB: WWW.SEECHANGE.IIT.EDU

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ABSTRACT

"SeeChange" is a web site that supports people who use frequency (count of a behavior per unit time) as a metric of behavior change or learning, such as in schools or rehabilitation. Users can enter data (behavior frequencies and text), have standard Charts (graphs) displayed on screen or printed, and archive data in the database. Files can be accessed to append or edit data. Authorized persons can view an individual's data on a 24/7 basis. Users can search for and retrieve particular target behaviors without personal identifiers. A "chat" feature will allow simultaneous viewing of a Chart and discussion. The site is designed to grow over time as users input data and use its methods to improve and evaluate outcomes of interventions, teaching, curricula and treatments.

BACKGROUND

"Learning" is commonly noted as a goal in rehabilitation (1, 2) education, and assistive technology (3). Logically, learning is an inference based on a change in behavior(s) documented across at least two measurement points. Measuring this change would allow comparison of learning under different conditions and allow the management of treatments for cost-effectiveness and the optimization of learning for individual clients.

When the frequency (count per minute) of a specific behavior is measured, we may define learning as the change in frequency over time (count/time/time). Clinical users of this method often count both "correctly" and "incorrectly" performed target behaviors during a timing interval, and plot both "frequency correct" and "frequency incorrect" performances. Thus we may discuss goals as "accelerating" or "decelerating" behaviors. Learners find the process empowering because the data are easily seen as objective and non-accusatory; learners can "try it again" until the team finds optimum conditions for performance.

These data plot on Change Charts (3), semi-log graphs that show count per minute against calendar days. Since human frequencies range across only about six log cycles (from .001/minute to 1000/minute), a standardized graph offers numerous advantages clinically. First, since it is absolute and usual frequencies of any behavior are found in a narrow range, one is alerted immediately to unusual data. Second, the variability is equalized across the graph. Third, straight line predictions are usual, whether the case is static (no change) or making great progress. Thus, we can see progress and the likely outcome while there are still resources left to try different tactics. Fourth, parallel lines represent equal progress, so that one can compare the celerations a given client is making across all rehab goals, or compare progress across multiple clients, to evaluate tactics.

PROBLEM STATEMENT

A problem is that most clinics and schools are not paid according to how much change each learner shows during treatment, so administrators have more incentive to provide the least expensive service than the most effective. A difficulty with the paper-based Change Chart is that graphs are not easily accessible to administrators, family members, or others. Clinicians and teachers who use Change Charts often use more interventions and materials because they see ineffective tactics sooner. However, most people working in rehabilitation and education do not understand graphs and institutions have no reason to support the "extra" work of graphing or data collection. Also, data accrued at one place are unavailable to other clinicians, families, or researchers.

RATIONALE

It seemed to us that a web-based solution to these issues would be feasible, useful, and inexpensive. Hence we are developing, implementing, and exploring the SeeChange site.

DESIGN

Functional system requirements are direct. Users must be able to set up, enter and revisit files. Data entry must be simple and flexible, so clerks, clients, and others with little experience can enter data easily. Data must be kept secure but accessible. Personally identifying information must be private, yet Charts of any target behavior should be retrievable by anyone.

Graphic output must conform to the aspect ratio of the Change Chart across any monitors and printers. A given file must be retrievable by a range of viewers, such as physicians, parents, principals, Special Educators, clinical supervisors, clients and advocates. A variety of data analysis tools are also needed. For example, a team may be keeping dozens of data files on a given client. At conferences, it is desirable to superimpose the data from a subset of these files on one display, so that the interventions providing the greatest change can be identified and replicated while those having less success can be changed. Similarly, a principal may wish to view periodically all of the data from each class, such as Mrs. Smith's Special Education arithmetic class. Thus, viewers must be able to keep "custom" arrangements and previously arranged groups of learners constant from session to session. The system must be able to "grow" new analysis tools, because its capability to visualize data has never before been available, and we cannot predict what will be effective or efficient for viewers. Technical requirements are also simple. The system must run on all hardware commonly found in schools (PCs and Macs) and provide fast updates and minimum internet traffic. In addition, users have asked that we standardize an international data file interchange format, so that persons developing software to address learning can use the site to provide graphing for their applications.

DEVELOPMENT

The database was initially designed in an Interprofessional Project for engineering majors at the Illinois Institute of Technology's Rehabilitation Engineering Technology Laboratory. After two semesters, a prototype system ran that took data in and returned back a version of the Change Chart. The current system is based on Symantec's standard commercial database using miniSQL and Java. A fourth iteration will use IBM's DB2 database, running under Linux.

EVALUATION

Professionals from several areas of learning have agreed to assess the system and provide formative feedback to the programming and design team during Spring, 2000. Behavioral consultants serving children with disabilities in the US, Canada, Australia, and New Zealand will use the system as an aid to providing ongoing management to clients at home while minimizing travel time and expense. Parents currently collect and fax data and the clinician-consultants review it and discuss changes in tactics by phone or email weekly. However the faxing is problematic due to smearing, faint images, and extraneous marks and the expense precludes daily updates. Instead, parents will simply input data to the SeeChange site for clinicians to access. Another group includes six teachers and their administrators of a school district in Illinois, and a Special Educator with a specialization is assistive technology. Finally, subscribers to the Change Chart listserv are invited to contribute comments and data.

DISCUSSION

One barrier to cost-effective services in rehabilitation and education is that institutions don't measure learning and are not reimbursed for inducing learning; while costs can be seen by any administrator, benefit is not quantified. While frequencies of most behaviors important to rehabilitation can be measured (4,5) precise and useful data about each individual has previously not been accessible to stakeholders. Clinicians and teachers who have collected such data find themselves doing extra intervention, measurement, and analysis work which may not be rewarded commensurate with the outcomes achieved. The SeeChange website will allow all stakeholders in learning, such as clinicians, clients, parents, physicians, teachers, administrators, and learners, the opportunity to see progress on an ongoing basis. Sophisticated administrators will be able to "see change" and rearrange administrative structure to help clinicians work with learners to induce change. Finally, frequency data empower learners to improve.

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Prediction of Calf Volume Changes at Different Levels of Voluntary Contractions of the Lower Limb Muscles

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ABSTRACT: The specific aim of this study was to find the correlation between plantar flexion contraction and the calf volume changes at maximum voluntary contraction (MVC), 80% of the MVC and 60% of MVC. An electronic plethysmography instrument (EPI) was designed and used to measure calf volume changes associated with various muscle contractions. The results demonstrate that EPI is a reliable tool for predicting calf volume change. The reliability α-correlation coefficients between the calf volume changes and different percentage of MVC were (MVC: 0.98; 80% MVC: 0.91; 60% MVC: 0.98). The correlation between the three levels of plantar flexion and the calf volume changes was found to be significant (MVC: $r=0.42$, $p<0.011$; 80% of MVC: $r=0.41$, $p<0.013$; 60% of MVC: $r=0.50$, $p<0.002$). The calf volume changes also correlate significant with calf shapes at the upper calf: $r=0.55$, $p<0.0002$; Middle calf: $r=0.58$, $p<0.0007$; and lower calf: $r=0.55$ $p<0.002$. The results of this study indicate that intensity of muscle contraction could be predicted by volume changes in the muscles and EPI is a reliable tool to be used for this purpose.

BACKGROUND: Functional electrical stimulation (FES), has been used for restoration of muscle function[1,2]. The determination of the optimum stimulation intensity for inducing desired muscle contraction has been a challenge for clinicians and investigators[3]. Most investigators use FES to induce specific muscle contractions using their own judgment to increase or decrease stimulation current in order to activate muscle motor points. As a result, the muscle may be under or over stimulated. Under stimulation may result in failure to reach a desired muscle contraction and over stimulation may lead to premature fatigue.[3,4] In order to eliminate early muscle fatigue, yet assure sufficient muscle activation, an index of stimulation intensity related to optimum muscle performance is required. An understanding of volume changes in normal human muscle in relation to different levels of voluntary contractions will aid researchers in utilizing FES more appropriately. To date, there are no published studies involving calf volume changes at various levels of voluntary contraction (VC).

RESEARCH QUESTION: The purpose of this study was to develop a device called an Electronic Plethysmography Instrument (EPI) and use it to measure the calf volume changes during various intensities of muscle contraction. The specific objectives of our study were to 1) establish the reliability of the EPI in detecting the volume changes in the limb, and 2) to see if the changes in the volume of the limb as indicated by the EPI correlate with different intensity of the muscle contractions.

METHOD: The design of the EPI device consisted of three májor parts: cuff transducers, pressure sensor and amplifier, and display. The cuff transducer function allowed for compressibility of air within the cuff and connection tubes and elasticity of the cuff. Pressure sensors and amplifiers responded to resistance change within the strain gauge cuffs leading to changes in output voltage directly proportional to applied pressure. A Honeywell 1400 Thermal strip chart recorder was used to record output and collect data. <u>EPI Calibration</u>: Two methods of calibrations were used to ensure accurate measurements for the study. The calibration procedure consisted of an air volume control bar and a water container specially designed for this study. Using the formula $\Delta p=k\times\Delta v$, changes in pressure and volume were rerecord for both the air and water. Each calibration procedure was repeated ten times for each condition with similar results. The coefficient (K=1.9) was used for our measurements.

Procedure: Nine subjects participated in the reliability testing and 30 participated in the correlation testing. All subjects signed an informed consent form in accordance with the University of Connecticut. Subjects were asked to sit in the test chair with their forefoot touching the pre-adjusted dynamometer plate. Three areas of the calf were measured and marked as lower, middle and upper calf circumferences. The ankle was set at 90 degrees and the knee was flexed and secured at 5 degrees. Adjustments for different leg lengths were made by manipulating the frame support tube to allow for proper leg positioning. These procedures minimized movement of the upper segments of the body, and muscles that cross the knee and ankle joints. Each subject was familiarized with performing maximum voluntary contraction on the dynamometer, and performed maximal plantar flexion contraction with the cuffed leg with three minutes of rest between MVC. The pressure cuff was refilled with air to a measure of 60mm and re-aligned and secured on the reference mark of the upper calf muscle. The researcher recorded the contraction force displayed on the dynamometer. Corresponding calf volume changes were recorded on the EPI in millivolts. The subject then performed 80% MVC where each subject attempted to reach 80% of MVC by using the index table that was previously calculated. The procedure was repeated for 60% of the maximum contraction force. (80% and 60% MVC determined by using index of number percentage).

STATISTICA L ANALYSIS: Pearson's produce moment correlation coefficient was used to test the reliability of the EPI, as well as the correlation between the calf volume changes and three levels of plantar flexion contractions. Least Significant Differences (LSD) was performed following the Analysis of Variance (ANOVA) to detect the significance at three levels of contractions using SPSS. The significance level was set at $P \leq 0.05$.

RESULTS: 1) Reliability Test. α-correlation coefficients between the calf volume changes and different percentage of MVC was found to be highly correlated, (MVC: 0.98; 80% MVC: 0.91; 60% MVC: 0.98) (table 1).

Table 1. Test-retest reliability data for EPI at 3 levels of contraction

	MVC			80%			60%	
ID	Test 1	Test 2	T1-T2	Test 1	Test 2	T1-T2	Test 1	Test 2	T1-T2
Mean	14.5	14.5	0	8.8	9.2	-0.416	5.34	5.5	-0.167
Variance	5.313	5.188	0.219	2.548	3.9097	0.7196	1.6563	0.9375	0.438
S.D	3.26	3.221	0.661	2.258	2.7963	1.1997	1.82	1.3693	0.935
Correlation Coefficient.			α=0.98			α=0.94			α=0.99

2) Correlational Analysis. Pearson product moment correlation analysis used to evaluate the relationship between different levels of contraction and calf volume changes (table 2).

Table 2. Correlation Between Force and Calf Volume Change at Three levels of VC (N=30)

Treatments	Plantar flexion force (lbs)		Volume Change (ml)		
	Mean	SD	Mean	SD	Pearson r
Max voluntary contraction	173	30.5	14.7	4.88	r =0.42, ***p<0.011***
80% Max voluntary contraction	135.9	25.49	9.01	3.75	r =0.41, ***p<0.013***
60% Max voluntary contraction	104.5	19.85	5.4	2.4	r =0.50, ***p<0.002***

3)Relationship Between Calf Volume Change and Calf Shape. Individual calf volume changes as well as force produced during three different levels of plantar flexion were highly correlated with individual calf circumferences measured at the upper, middle and lower calf (table 3).

Table 3. Correlation Between the Calf Shape and Three Levels of VC (N=30) *P< 0.05

Treatments	Upper Calf	Middle Calf	Lower Calf
Pearson R	Pearson r	Pearson r	Pearson r
Maximum voluntary contraction	0.54*	0.60*	0.55*
80% voluntary contraction	0.60*	0.70*	0.61*
60% voluntary contraction	0.67*	0.50*	0.60*

DISCUSSION: The results of this study indicated that designed EPI is highly reliable tool to measure the calf volume changes. There is also significantly high correlation between calf volume changes and plantar flexion contraction at various levels of contractions as indicated by EPI. Although the correlation coefficients are not as high as expected, they are significant. Previous study by T. Funkunaga[4], using magnetic resonance imaging found that the force transmitted to the Achilles tendon (tendon tension) was highly correlated (r=0.93) to the total physiological cross-sectional area (PCSA) of the calf. This high correlation lends support to our hypothesis that calf volume changes are related to the force of plantar flexion. When the PCSA of all of the plantar flexors were correlated with the force, the correlation did not improve (r=0.92) [5]. This finding indicates that isolation of specific plantar flexors is not necessary for determining tension force. Thus, supporting the procedure of this research in testing all plantar flexors together. Therefore, it appears that when comparing the EPI with the gold standard for measuring the cross sectional area of the leg (MRI), the EPI and MRI show the same relationship.

CONCLUSION: The results of this investigation demonstrate that EPI is highly reliable and can be a simple tool to measures calf volume at various levels of muscle contractions. The statistical data showed a significantly positive correlation between calf volume changes resulting from various levels of muscle contractions. This system may be used in conjunction with FES to predict the desire muscle contraction based on the volume changes in the contracted paralyzed muscle.

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DISTINGUISHING CHARACTERISTICS OF PARKINSON'S SIT-TO-STAND USING ACCELEROMETRY

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ABSTRACT

The goal of this study was to distinguish characteristics of sit-to-stand (STS) performed by Parkinson's disease (PD) subjects compared to healthy elderly (HE) using accelerometry. Twenty HE, and 14 PD subjects performed STS. Variables derived from the accelerometric vector magnitude at right and left waist were calculated. The average of four trials was compared for associations between variables using Pearson product moment correlations. Most interestingly, an inverse association between accelerometric vector magnitude during seat-off (S.O.) and STS duration was found for PD subjects.

BACKGROUND

STS has been studied as a test of postural steadiness in various subject populations (1,2,3,4). Bloem, et al. found that a prolonged duration of STS was a better indicator of dopa-sensitive abnormality in PD than static posture and gait measures (1). We will compare PD with HE STS using accelerometry. We developed a Wearable Accelerometric Motion Analysis System (WAMAS) which will ultimately be a balance orthosis that monitors physical balance and aid in fall prevention. Triaxial (X-, Y-, Z- axes) sensors on the WAMAS consist of three single accelerometers ($\pm$5g) mounted with sensitive axes orthogonal to one another. The current model can record data from up to four sets of these triaxial accelerometers, of which two can be mounted on eyeglass frames and two at the waist above the hips to measure upper body motion (5). Only waist sensors were used in this study. A clear understanding of deviations from "normal" accelerometric signal characteristics can provide clinicians with a therapeutic tool for PD.

METHODS

Twenty HE subjects (5 males, 15 females; 74.5yrs., sd=$\pm$5.5) with no known balance deficits and fourteen subjects with PD (9 males, 5 females; 67.3yrs.,sd= $\pm$5.4) were tested wearing the WAMAS. Subjects were asked to perform STS at normal speed with arms crossed at the chest while split-screen video of the frontal and sagittal planes and accelerometric data were recorded. Chair height was adjusted to popliteal height. Each trial was repeated four times.

Data Analysis: STS has been defined to consist of four stages (6,7,8): (a.)Flexion momentum [FM] = upper body bends forward; (b.)Momentum transfer [MT] = when primarily forward momentum is transferred to upward momentum and includes S.O., (c.)Extension [EXT], and (d.)Stabilization [STAB].

S.O. was time-matched from video to the averaged right and left waist accelerometric vector magnitude ($|V|=\mathrm{sqrt}(X^2+Y^2+Z^2)$) of the body sensors ($V_{S.O.}$). With HE, it corresponded with the maximum vector magnitude, while for PD, it tended to correspond with the first peak preceding the minimum. The minimum of the vector magnitude corresponds with the end of the extension stage before deceleration. Again, using the averaged accelerometric vector magnitudes, the following variables were calculated: minimum (V_{min}), time between the start of motion and the minimum (t_{min}-t_0), time between start of motion and S.O. ($t_{S.O.}$- t_0), and time between S.O. and the minimum (t_{min} -$t_{S.O.}$) [Fig. 1].

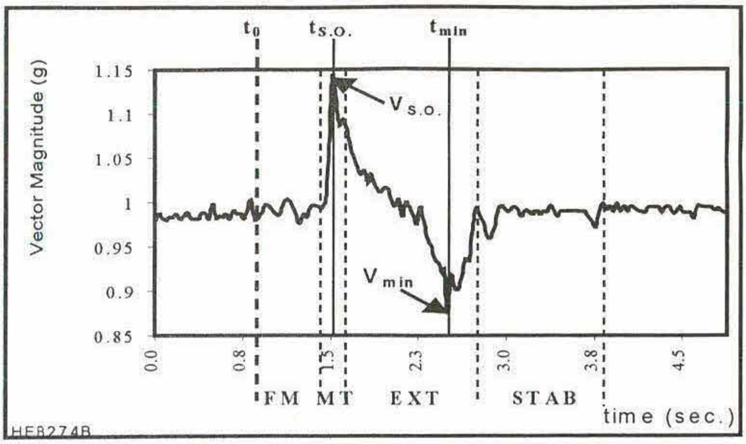

Figure 1. Sample (HE) STS displaying time markers and stages.

Pearson product moment correlation tables for HE and PD subjects were generated for the above variables to determine strength of associations.

RESULTS

Table 1 lists the Pearson product moment correlation coefficients for HE subjects. Only t_{min}-t_0 and $t_{s.o.}$- t_0 were significantly positively correlated ($p<0.005$).

Table 1. Pearson Product Moment Correlation Table for HE Subjects

Healthy Elderly	$V_{s.o.}$	V_{min}	t_{min}-$t_{s.o.}$	$t_{s.o.}$-t_0	t_{min}-t_0
$V_{s.o.}$	1	0.284	0.037	-0.561	-0.47
V_{min}		1	0.631	0.303	0.537
t_{min}-$t_{s.o.}$			1	0.082	0.505
$t_{s.o.}$-t_0				1	**0.901**
t_{min}-t_0					1

Table 2. Pearson Product Moment Correlation Table for PD Subjects

Parkinson's	$V_{s.o.}$	V_{min}	t_{min}-$t_{s.o.}$	$t_{s.o.}$-t_0	t_{min}-t_0
$V_{s.o.}$	1	-0.611	-0.511	**-0.798**	**-0.739**
V_{min}		1	0.526	0.488	0.546
t_{min}-$t_{s.o.}$			1	0.689	**0.885**
$t_{s.o.}$-t_0				1	**0.948**
t_{min}-t_0					1

Table 2 lists the Pearson product moment correlation coefficients for PD subjects. $V_{s.o.}$ is negatively correlated to $t_{s.o.}$-t_0 and t_{min}-t_0, and t_{min}-t_0 is positively correlated with $t_{s.o.}$- t_0 and t_{min}-$t_{s.o.}$ ($p<0.005$).

DISCUSSION / CONCLUSIONS

For HE subjects, a strong correlation ($r=0.901$, $P<0.001$) was found between t_{min}-t_0 and $t_{S.O.}$-t_0. The interval $t_{S.O.}$-t_0 includes forward flexion of the upper body (FM) until just before S.O. occurs. This interval is part of t_{min}-t_0. This association suggests that when t_{min}-t_0 increases, it is due to an increase within the interval $t_{S.O.}$-t_0 and not t_{min}-$t_{S.O.}$. However, for PD subjects, both $t_{S.O.}$-t_0 and t_{min}-$t_{S.O.}$ are strongly associated ($r=0.948$, $P<0.001$; $r=0.885$, $P<0.001$, respectively) with t_{min}-t_0. We suspect that this difference between the HE and PD subject data results from a greater range of performance by PD subjects (i.e., some PD subjects perform well below the range of HE subjects). The mean t_{min}-t_0 for HE and for PD were equal, but the standard deviation for PD was much greater than for HE (HE mean=1.41sec, sd=0.28; PD mean=1.41sec, sd=0.43). The source of this variability can be from many factors (i.e., time since last dosage of medication, effectiveness of medication on particular subjects, impaired ability to perform consistently). Such factors need to be documented independently.

Interestingly, in PD subjects, $V_{S.O.}$ was negatively correlated with $t_{S.O.}$-t_0 and t_{min}-t_0. This suggests that a PD subject who requires more time to rise is less able to achieve the acceleration needed at S.O. for the transfer to upward momentum.

According to Bloem, et al. (1), a longer STS can be an indicator of dopa-sensitive abnormality in PD. Such an association between HE vs. PD STS in the accelerometry signal can be used as one of the criteria for efficacy of therapeutic intervention of PD by clinicians.

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MEASUREMENT OF STEP MAXIMUM AND AVERAGE FORCE AND DURATION TO PREDICT FOOT ULCERS

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ABSTRACT

A device has been developed to monitor and record the repetitive stresses applied to pressure sensitive locations under the foot. This device targets individuals who suffer from diabetes and are at risk for foot ulcers. Data collected is downloaded into a central database for correlation of the data with the clinical observations of ulcer formation. Based on the correlation results, the device will provide feedback to the patient and the health-care practitioner. The feedback to the patient will be used to augment their protective sensation, while feedback to the clinician will be used for evaluation of percent efficacy of the orthosis and the risk level of the patient. The present prototype can record data for over 2 weeks without a battery change or data download.

BACKGROUND

An estimated 16 million people in the United States suffer from diabetes (1), which is a major cause of peripheral neuropathies and amputation of the lower extremities (2). The presence of infections in the diabetic foot is an especially important clinical problem because lower extremity infections are one of the most common reasons for hospitalizing diabetic patients. The average medical cost for a diabetic patient with a foot infection is $45,000. This does not, however, cover the indirect costs including the expense of disability payments, prostheses, rehabilitation, loss of income, and frequently, lost jobs. According to the Center for Podiatric Information, this can total as much as $47 billion dollars in one year alone (3).

Diabetic foot ulcers and amputations are among the worst disabling complications of diabetes. At least 15 percent of all people with diabetes eventually develop a foot ulcer (4). These ulcers frequently become infected and lead to amputation so frequently that 6 out of every 1,000 people with diabetes have an amputation (4). Once the amputation of one limb has occurred, the prognosis for the contralateral limb becomes poor (5). At least 30% of all diabetic amputees lose the contralateral extremity within 3 years. In the U.S. alone, 54,000 diabetes-related amputations are performed costing more than 600 million dollars. After major amputation of a lower extremity, two thirds of patients die within 5 years (3). These outcomes can, however, be prevented if the natural feedback mechanisms could be restored to the diabetic individual. The long-term goal of this project is to provide a substitute for some of these feedback mechanisms.

RESEARCH OBJECTIVE

The objective of this work was to build a device that can monitor and record the pressures of high-risk locations under the foot to provide feedback to both the patient and the clinical practitioner. It is not yet clear what specific patterns of foot pressures cause foot ulcers to begin. Therefore, the recorded data is being compiled into a database that will allow us to extract how different factors are correlated with ulcer formation. Once these factors have been quantified, an algorithm will be formulated to produce either an audible or a tactile feedback to the patient when the individual has reached a level that puts them at risk for developing a pressure ulcer. The immediate goals for this project were to construct a device that can:

a) Log force data from a sensor placed under the user's foot for at least one week.

b) Download the data to a central database
c) Present the data for visual review and analysis

METHOD

The device has three main components: sensor, hardware and software, each of which will be addressed individually. The sensor chosen was a FlexiForce™ sensor that was embedded inside of an insole with the sensor located under the 1st metatarsal of the foot. The insole consisted of two flexible Lexan™ sheets (0.25mm) custom cut to fit the patient's shoe.

The hardware had both an input for the sensor and a serial link. The serial link was used to both download data from the device and to set parameters stored in the device including a patient ID, the time and date, and threshold value. The firmware had two data acquisition modes: raw data and step data. The raw data mode was used if the threshold was set to 0 (the default for a new device). In the raw data mode, every force sample (at 20Hz) was stored, while step mode recorded only specified events. An event was noted when the force crossed the defined threshold (in either direction) or when a timer from the previous event ran down to zero. In either case, each event recorded the total duration since the last event along with the corresponding maximum force and the average force during that interval. Data was therefore recorded for every stance and swing phase individually. In the absence of a threshold crossing (e.g. no change in the load), the device logged the maximum and average force during each 54.6 minute interval (the maximum time duration).

The database software allows the clinician to add new patients, set the device and download the data. Each patient was entered with relevant information including birthdate, foot size, foot anomalies, level of sensory and vascular deficits, and history of ulcers. Both raw and step data are then stored for the particular patient. The raw and step data can then be viewed online by the clinician to determine the efficacy of the orthosis, the threshold to be used to define a step, the activity of the patient, and the potential patient risk level.

RESULTS

The device was constructed and programmed to perform both 'raw' and 'step' data recordings. The device is 4 ¾" x 2 ½" x ¾" and weighs 101g (3.6oz) including the battery. Although both 'raw' and 'step' data have been collected using this device, it is too soon to extract any information correlating the formation of ulcers to any parameter. The 'raw' data was found to correlate directly with the patient activity during walking, jumping, crouching, and split weight stance. An example of 'raw' data, shown in Figure 1 left, shows an example of 2 periods of standing in place and 3 sets of 3 steps each. The 'step' data was performed over the course of a week and corresponded to periods of activity and relaxation as recorded by the patient in a custom diary. A small example of 'step' data, shown in Figure 1 right, illustrates a similar 2 periods of standing in place and 3 sets of 3 steps performed in the example of 'raw' data. Although the actual data at each point in time is not shown by the 'step' data, the overall pattern and level of activity is shown.

The patients gave us positive feedback and indicated that the device was neither cumbersome nor difficult to wear. In general, the foot insole was not noticeable. Only one electrical connector failed during the trials. This connector has since been reinforced.

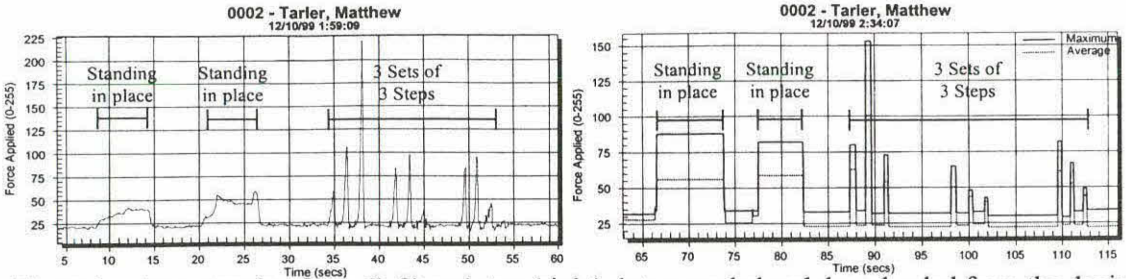

Figure 1 – An example of raw (left) and step (right) data recorded and downloaded from the device. In each case the user stood in place twice and then took three sets of three steps. The raw data shows the raw output (scale is 0-255) at 20Hz. The step data shows both a maximum (upper solid line) and an average (lower dashed line) output that was achieved over the duration of time indicated by the horizontal line.

DISCUSSION

The preliminary success of this device is very encouraging. The raw data was useful to a clinician as feedback on efficacy of various orthoses. The device can hold over 32,000 step events in its memory, which we estimate to be about 2 weeks of recording. With some minor improvements the recording time will be extended to 4 weeks. Since no intervention by the user is necessary (i.e. no battery change and no need to turn the device on or off) this device will be ideal for reliable collection of large amounts of data. A national database will be set-up so that each clinician can download their data to a central location. This central database will then be used to determine which factors in the step records correlate with the occurrence of pressure ulcers. With this information it will be possible to develop a variety of preventative measures, including a feedback device that would alert patients when they were at risk for ulcer formation.

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Seating and Mobility (Topic 8)

WHEELCHAIR SEAT CUSHIONS EVALUATION USING A FINITE ELEMENT MODEL

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ABSTRACT

Simulations of the interaction between the buttocks and a seat cushion were done using a finite element model to evaluate the pressure distribution at the cushion-buttocks interface. Eight seat cushion designs were developed and compared according to pressure distribution parameters. Cushions with a contoured shape showed better mechanical properties than the flat cushions, particularly by reducing the peak pressure, the maximal pressure gradient and by providing a more uniform pressure distribution. This new evaluation method is an alternative to clinical comparative studies by reducing development and experimental costs.

BACKGOUND AND OBJECTIVES

One of the most frequent problems for wheelchair users is soft tissue trauma related to long term loading by sustained external forces [1]. To prevent such problem, wheelchair users often use custom contoured cushions in order to distribute more adequately the pressure at the cushion-buttocks interface. However, this solution is not widespread due to the cost and expertise related to this type of cushion. A less expensive and simpler method consists of using commercially available cushions. To evaluate the effectiveness of a cushion for a given population, clinical experimentation is usually needed. Generally, the main objective criteria are the magnitude and location of maximum pressure as well as the overall pressure distribution. Such studies are limited to existing cushions, therefore it turns to be searches for the best cushions within restricted selections instead of overall optimized cushions. The high number of subjects and resources involved in such experimental studies is also a substantial drawback.

The objectives of this paper are to present a design study aimed to evaluate and compare different wheelchair seat cushion models in regard to the pressure distribution.

METHODS

From a general widespread design methodology involving seating experts, cushion design concepts were elaborated. Designs that presented the best potential were developed and assessed using a finite element model which enables the study of pressure distribution at the cushion-buttocks interface. The interface pressure was evaluated by comparing each proposed cushion design to a regular flat Neocor HR50 (Woodridge Foam Corp.) cushion. Eight seat cushion designs are presented in this paper (figure 2) where two correspond to commercially available cushions: a 76.2 mm (3 in.) thick Neocor HR50 flat cushion and a Iscus contoured cushion (Orthofab Inc.). The finite element model used was composed of a rigid buttock and of a foam cushion (figure 1). One buttock and half of the cushion were modeled due to symmetry in order to simplify the model. The cushion model had external dimensions of 203 mm x 457 mm (width x depth) and was meshed using 432 8-node brick elements suited for large deformation and nonlinear contact analyses. A mutilinear representation of different hyperelastic foams was used to specify the mechanical properties of those elements [2]. The buttock model was meshed using 994 surface

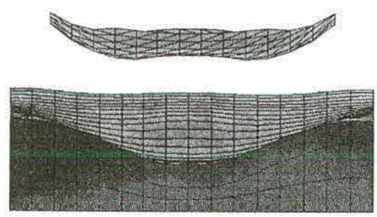

Figure 1: Finite element model of the buttocks and the cushion.

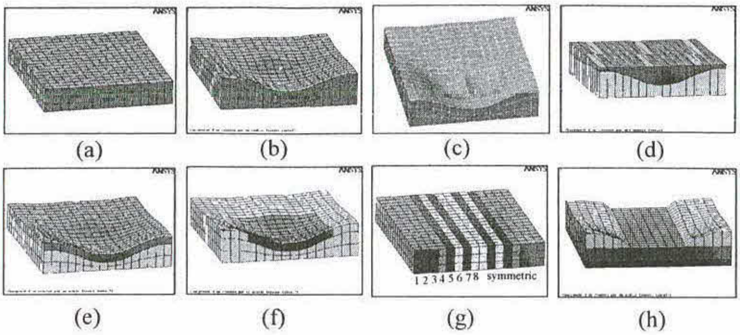

Figure 2: Cushion model description. a) ***Flat***: 76.2 mm slab of Neocor HR50; b) ***Iscus seat cushion*** (Orthofab Inc.) made of PU 310 Pa; c) ***Modified Iscus***: Iscus seat cushion with a 12.7 mm deeper hollow under the ischial tuberosities made of PU 310 Pa; d) ***Flat covered contoured***: The bottom layer shape corresponds to the Modified Iscus made of Super constructa foam (max. thick.: 76.2 mm) and filled on top with Neocor HR50 to produce a flat surface exceeding the upper part of the bottom layer by 25.4 mm; e) ***Covered contoured A***: The bottom layer shape corresponds to the Modified Iscus and is made of PU 310 Pa (max. thick. 76.2 mm) and covered by a 25.4 mm layer of PU 240 Pa; f) ***Covered contoured B***: Corresponds to the Modified Iscus with a 254 x 254 x 25.4 mm^3 cutout under the ischial tuberosities filled with PU 240 Pa. Its has a maximal thickness of 101.6 mm and is made of PU 310 Pa; g) ***Progressive***: Made of sixteen bands of four different foams (glued): 1^{st}-2^{nd}-3^{rd} in PU 380 Pa; 4^{th} in Neocor HR50; 5^{th}-7^{th} in PU 310 Pa; 6^{th}-8^{th} in PU 240 Pa; h) ***Modular contoured***: The top layer (side contoured) is made of PU 380 Pa and has a maximal thickness of 44.5 mm. The median layer is made of Neocor HR50 and has a thickness of 38.1 mm. The bottom layer is made of Super constructa foam and is 19.1 mm thick.

elements and acted as a load applicator on the cushion model. Its geometry was obtained by a seating shape measurement system (CASS, Seating and Soft Tissue Biomechanics Laboratory, University of Pittsburgh) and corresponded to the mean shape of the deformed buttocks of 30 elderly subjects in a seated position [3]. The dimensions of the buttock were normalized to correspond to a 120 mm inter-ischial distance. Two hundred and eight 4-node surface-to-surface nonlinear contact elements were used to represent the cushion-buttock interface in order to detect interaction and transmit the load when the buttock came into contact with the cushion during loading simulations. The computer simulations were conducted with the buttock model positioned so that the ischial tuberosities were at 140 mm from the rear edge of the cushion model, which corresponds to a usual clinical situation. In all simulations, nodes located on the bottom plane of the cushion model were constrained to represent a rigid support surface. A 207 N load, corresponding to 65% of the seated weight of a 50^{th} percentile elderly person, was applied downward on the buttock model. Friction between the buttock and the cushion surface was neglected. The stresses normal to the buttock-cushion interface, which correspond to the pressure often measured clinically [4], were extracted from the simulations. The maximal and mean values as well as the standard deviation, which gives an indication of the pressure distribution uniformity, and the maximal gradient were analyzed. Only stress values corresponding to pressure above 667 Pa (5 mmHg) were considered for calculations.

RESULTS

Results computed from the simulations showed that four of the five contoured type cushions give substantial lower values regarding the maximal pressure, maximal gradient and standard deviation of the pressure values than the flat type cushions (table 1). The four contoured cushions along with the *Progressive cushion* showed the lowest mean pressure. On the other hand, the *Modular contoured cushion* present the highest values for almost all the parameters.

DISCUSSION

According to computer simulations, the contoured cushions (figure 1b, 1c, 1e and 1f) provided a better support to the seated user than all flat type cushions regarding pressure distribution at the cushion-buttock interface. An exception was the *Modular contoured cushion*, which showed the worst results. As generally observed in clinical situations, the maximal and mean pressures were lower for the contoured cushion (*Modular contoured* excluded). The lower standard deviations shown by the contoured cushions also indicate a more uniform distribution of pressure at the cushion-buttocks interface as compared to the other cushions. Concerning the low maximal pressure gradients provided by these contoured cushions, one could assume that less soft tissue distortion would occur with the use of such cushions. These results may be explained mostly by the initial fit provided by their more conformant shape with respect to the buttock.

Table 1: Computer simulation results for the different cushion designs. Values are given as a ratio of the flat basis cushion results.

Cushion model	P_{max}	P_{mean}	Stand. Dev.	$Grad_{max}$
Flat (standard)	12.136 kPa	5.454 kPa	3.392 kPa	0.138 kPa/mm
Iscus	-24.3%	-16.7%	-32.9%	-38.8%
Modified Iscus	-33.4%	-15.5%	-41.9%	-52.1%
Flat covered contoured	-8.5%	+1.3%	-7.6%	-11.8%
Covered contoured A	-28.7%	-15.9%	-35.3%	-41.3%
Covered Contoured B	-33.9%	-15.8%	-40.3%	-38.4%
Progressive	-7.0%	-19.5%	-2.6%	-21.2%
Modular contoured	+10.0%	+13.5%	-3.0%	+96.3%

As a first analysis conducted using a finite element model, this study was limited in the quantity of designs evaluated, mainly in regard to the constitutive materials and the cushion shapes. Also, a unique geometry of buttock was used as load applicator which did not represent all buttock shapes and sizes of the whole population of wheelchair users. Consequently, this study gives an indication of the overall mechanical characteristics of the different seat cushion concepts but further simulations on other designs as well as asymmetric loading to represent other frequent clinical situations should be done before rejecting any particular concept. The rigidity conferred to the already deformed buttock did not provide information about how the stress and strain were transmitted through the buttock's soft tissues.

In contrast to the traditional clinical methods, this study was done using a computer model which has shown the feasibility to conduct efficient design comparisons of wheelchair seat cushions without the need of physical cushions and subjects. This method is faster, less expensive and has the possibility to conduct tests on virtual prototypes. However, the choice of a cushion made using the present approach need to be validated clinically on an appropriate group of wheelchair users.

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TECHNICAL ASPECTS OF PRESSURE MAPPING

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ABSTRACT

Technical aspects of Pressure Mapping are important to understand, so that this widely accepted clinical tool may be effectively used. It must be utilized with good clinical protocols and critical judgment in understanding the information derived. The ability to observe, measure and review the dynamics of pressure occurring at the seat interface is an invaluable addition to clinical practice [1]. Using an interface pressure mapping system, which records information during the dynamic activity of wheelchair seating, is clinically valuable [2]. Pressure Mapping enables the clinician to manage or prevent the problems associated with pressure such as poor positioning, poor function, non-compliance, discomfort, pain, redness, or development of outright pressure ulcers [3][4]. This investigation reviews pressure mapping technical concerns, with respect to the underlying physics and science. In particular, the issues seen as affecting the reliability, repeatability, and accuracy of this useful tool are identified, discussed and critiqued. Key issues identified are: Speed, average clinical setting using pressure mapping.

Background:

Wheelchair seating should promote a healthy, safe lifestyle. To achieve this a clinician must consider proper postural alignment and distribution of weight, balance and stability, and pressure relief [5]. Seating and positioning within a wheelchair is well understood to be a dynamic activity while previous methods of assessment tended to be subjective. Pressure Mapping demonstrates a quantifiable and reliable method to assess pressure distribution effectively. To adequately provide responsible treatment, the clinician must be able to understand and interpret these pressure patterns. Pressure mapping is a tool developed over the last fifteen years enabling the clinician to quantitatively and visually display the pressure distribution occurring at the seat/buttock interface [1]. This has proven to be a very useful tool in the clinic when assessing the individual [2]. The information provided by Pressure Mapping is seen as useful, but the technical aspects of how this information is derived and reasonable assurance of its' validity and reliability should be questioned and considered with respect to the challenges of the science underlying the tool.

Technical Issues:

There are a variety of Pressure Mapping systems available in the world. Each utilizes a combination of resources to gather and display the information received from the seat/buttock interface. All systems use three key components: a sensing surface; an electronics gathering device; and software to interpret and demonstrate the information. Although considerable variation in methodology is evident with the different systems, they all share the same underlying challenges. There are three most prolific types of sensing surfaces: air/fluid inflation sensors; piezo-resistive sensors; capacitive sensors. The electronics modules differ widely, but all accomplish the same task, to electronically address the array of sensors to gather the raw data captured from the seat/buttock pressures. This information is then sent to the computer software, which interprets, organizes and displays the derived information in a visually acceptable format for clinical use. Key issues along this path of data gathering, which can affect the validity of the output are: Speed, Spatial Resolution, Hysteresis, Creep, Temperature, and Humidity. How this information is gathered and interpreted ultimately affects the reliability, repeatability and accuracy of the output pressure mapping information.

Speed (temporal resolution): The type of sensors used fundamentally limits the number of sensors that can be read. per

Spatial Resolution: The number of sensor per square inch determines the features that can be resolved. This issue breaks down into the desire to resolve anatomical or smaller features.

Hysteresis: The direction of loading (increasing or decreasing pressures) has an affect on the readings. Increasing pressure tend to be under read while decreasing pressures tend to be exaggerated. See Figure 1.

Creep: The tendency for the readings to increase with time is the largest contributor to pressure mapping system error and results from the compromise for flexibility. As sensors are made softer and more conformal there tends to be an increase in the tendency to creep. See Figure 2.

Temperature: Increases in temperature generally give rise to increase output for sensors since the elevated temperature extends the creep characteristics of the sensors. This affect is however normally minimal.

Humidity: To the extent that the sensors are isolated from the environment humidity effects are minimal.

Reliability, Repeatability, Accuracy: Other contributors to the overall, reliability, repeatability and accuracy of the sensors systems are:
Non-linearity
Analog to digital resolution (8 bit vs. 12 bit etc.)
Calibration techniques and frequency
Care and handling of the equipment
Data management and interpretation

Conclusion:

Pressure mapping allows the practitioner to view the pressure changes occurring during seated activity; to determine peak pressure sites and quantities; to compare different seat cushions; see effects of posture changes and/or wheeling techniques. The visual display provides a method of feedback to the client, clinician and other clinicians. An understanding of the underlying technology allows the clinician or researcher to use these tools in their most effective and productive ways.

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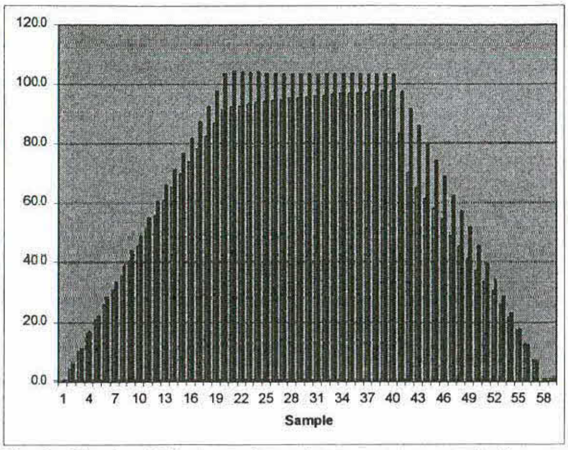

Fig 1. Typical Hysteresis and creep uncorrected

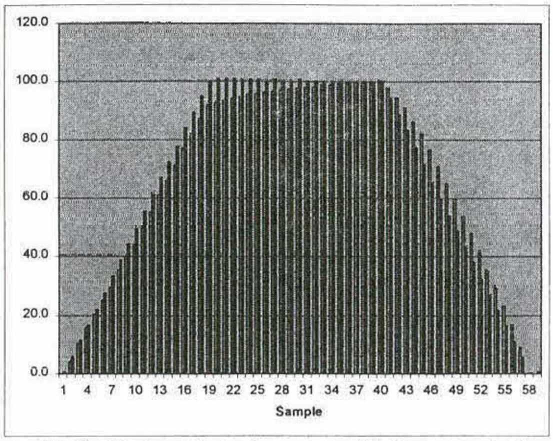

Fig 2. Hysteresis and creep partially corrected

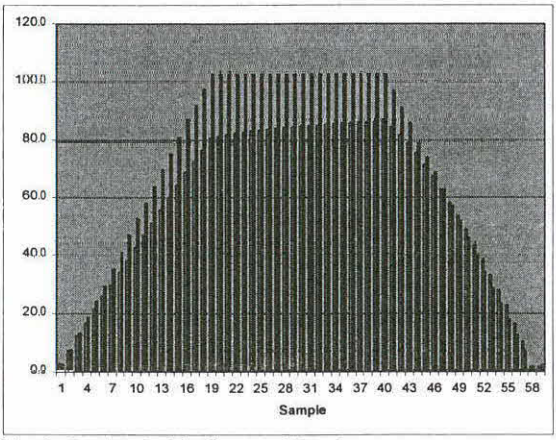

Fig 3. Preloaded before calibration

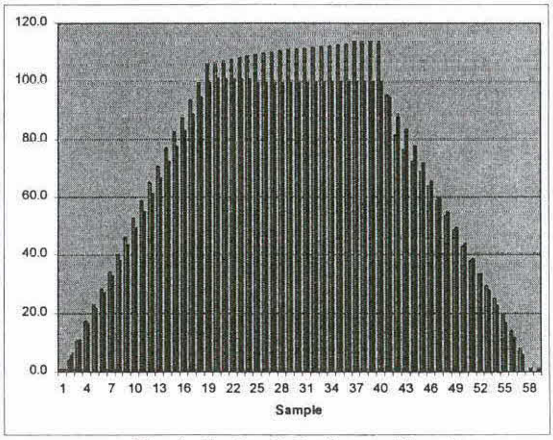

Fig 4. Preloaded after calibration

Dark = Average Sensor Pressure Light = Actual Pressure

THE EFFECT OF PRECONDITIONING ON THE REPEATABILITY OF QUASI-LINEAR VISCOELASTIC PROPERTIES OF BUTTOCKS SOFT TISSUE

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ABSTRACT

A novel means of determining individuals susceptible to pressure ulcers is the development of biomechanical criterion specific to at risk tissue. The biomechanical evaluation of soft tissue necessitates the collection of repeatable measures. A method of obtaining these measures is preconditioning tissue before trials are performed. The effect of preconditioning on the repeatability of the quasi-linear viscoelastic model was evaluated in this investigation. The Computer Automated Seating System (CASS) was utilized to obtain soft-tissue data from subjects (force, pressure, tilt angle, tissue thickness, time). Analysis of this data showed that a more repeatable response occurs with tissue that has been preconditioned before testing.

BACKGROUND

Development of pressure ulcers on the buttocks of wheelchair users is a widespread problem. It has been found that between 50% to 80% of persons with spinal chord injuries will develop a pressure ulcer (1).

A way of exposing at risk individuals is to gain some knowledge of the differences in the biomechanical properties of the soft tissue of those who suffer from pressure ulcers and those who do not. A common method of modeling biomechanical properties of soft tissue is the use of Fung's quasi-linear viscoelastic (QLV) theory. The QLV theory has been found to be a viable method for determining the viscoelastic properties of ligaments and tendons (2,3).

The quasi-linear viscoelastic theory assumes that the stress relaxation function is dependent on both extension and time and can be expressed as:

$$\sigma[\varepsilon(t);t] = G(t) * \sigma^{e}(\varepsilon) \qquad G(0) = 1$$

Where σ^e is the "elastic response" (a function of strain only) and G(t) is the reduced relaxation function (a function of time). The stress at time t, $\sigma(t)$, is the convolution integral between the reduced relaxation function and the rate of elastic stress. With G(t) and $\sigma^e(\varepsilon)$ known, the entire stress history is described by the above convolution integral (3).

Previous experiments have shown that the internal structure of tissue changes with cyclic loading. After repeated cycling, a steady state is reached at which no further change will occur in tissue structure unless the cycling pattern is changed. In this preconditioned state, tissue has been found to exhibit more elastic stiffness and a reduced instantaneous viscoelastic response compared to tissue that has not been preconditioned (3,4). When tissue exhibits these properties it is said to be pseudo-elastic (3).

RESEARCH QUESTION

The goal of this investigation was to determine the effect of preconditioning on the stress relaxation response of buttocks soft tissue. Previous studies have shown that a repeatable stress relaxation response can be achieved after a cyclic preconditioning routine. This investigation makes certain that the response of preconditioning of the buttocks soft tissue produces a repeatable response in the tissue, and that this response is similar to those previously documented for other tissues.

METHOD

Collection of Data

An able bodied subject was first seated on the CASS. The subject was positioned so that a CASS transducer was located 4 cm distal to his ischial tuberosity. This transducer was then elevated at a velocity of 1.058 mm/sec, held at a relative indentation of 20% of the bulk tissue for 300 seconds, and then unloaded at a velocity of 1.058 mm/sec. Data was collected throughout this period of loading. For trials not involving preconditioning this procedure was repeated three times.

For trials involving preconditioning the subject was first seated on the CASS as described above. However before the loading procedure was begun a preconditioning routine was performed. Preconditioning involved loading the tissue in a cyclic fashion for 12 cycles, alternating between 30% compression of bulk tissue and no compression (zero force). After preconditioning, the loading procedure was performed. This procedure was repeated three times.

Data Analysis

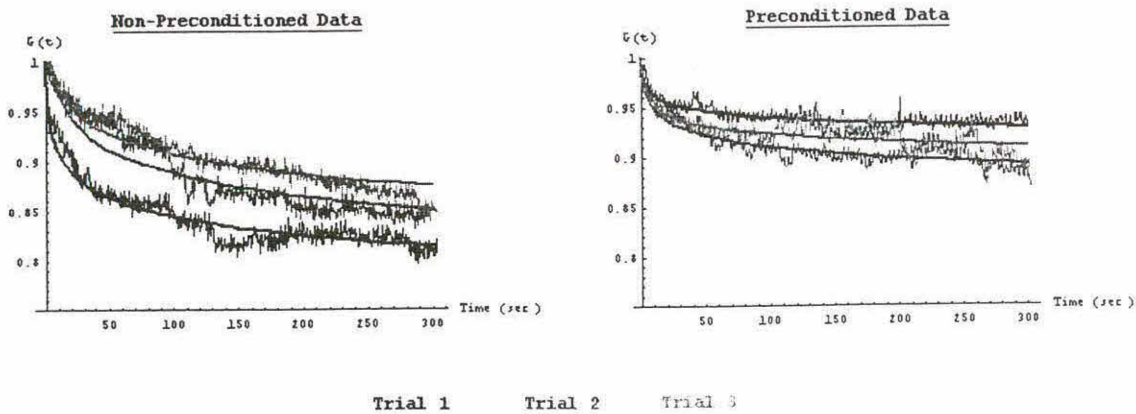
For this investigation G(t) was defined as follows, where γ is Euler's constant:

$$G(t) = \frac{1 - C\gamma - C\ln(\frac{t}{\tau_2})}{1 + C\ln(\frac{\tau_2}{\tau_1})}$$

τ_1 represents the instantaneous viscous phenomenon of the tissue, τ_2 represents the slow viscous phenomenon of the tissue, and C represents the reduction in amplitude of G(t). A linear regression was performed to determine the material constants τ_1, τ_2, and C. The percent relaxation of the tissue was also calculated.

The mean was determined for each parameter in each group (i.e. preconditioned group, non-preconditioned group). The mean values for each parameter were compared.

RESULTS



	Non-Preconditioned Data					Preconditioned Data				
	C	τ_1	τ_2	Percent Relaxation	R^2	C	τ_1	τ_2	Percent Relaxation	R^2
Trial 1	0.0315	0.6573	48.4585	18.2	0.86	0.0104	0.3890	81.9648	6.9	0.85
Trial 2	0.0371	7.01241	53.2858	14.4	0.79	0.0179	0.8118	68.1337	10.6	0.75
Trial 3	0.0315	7.7616	59.7413	12.1	0.81	0.0130	0.3262	74.8829	8.8	0.80
Mean	0.033	5.144	53.829	--	--	0.014	0.509	74.994	--	--

DISCUSSION

Noticeable differences were found amongst the parameters of the QLV model. A decrease in parameter C, the value governing reduction of the reduced relaxation function, was found between non-preconditioned and preconditioned tissues. This decrease corresponded to a lesser relaxation of the tissue. A decrease in the τ_1 parameter between non-preconditioned and preconditioned tissue was also exhibited, indicating a reduced effect of the instantaneous viscous phenomenon of the preconditioned tissue. An increase in the τ_2 value for preconditioned tissue was seen due to a greater influence of the slow viscous phenomenon of the tissue. Overall, preconditioning tissue resulted in a more repeatable tissue response and a smaller percent relaxation of the tissue. These characteristics were similar to those previously documented (3).

It should be noted that although no cyclic preconditioning procedure was performed for non-preconditioned tissue, it exhibited a preconditioned response after successive loading. The decrease in the percent relaxation after repeated loading can be attributed to an increase in elastic stiffness due to tissue deformation; in essence the successive loading of the tissue exhausted its instantaneous viscous response to deformation so that the response exhibited was one similar to an elastic solid. This phenomenon is described as pseudo-elasticity. Results of this investigation show that preconditioned buttocks soft tissue can exhibit pseudo-elastic behavior.

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MEASUREMENT OF SITTING PRESSURE UNDER THE ISCHIUM: A RELIABILITY STUDY

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ABSTRACT

Locating areas of high pressure, at the chair buttock interface, is useful in predicting the site at risk of developing tissue breakdown or sitting discomfort. Before making such predictions, it is necessary to identify reliable sitting pressure parameters for objective critical evaluation of pressure distribution. This paper describes a methodology that provides a reliable representation of the pressures within the rectangular region under the ischial tuberosities. The mean peak pressure of nine sensors, with the greatest pressures, over a 3x3 block, has been found to be a very reliable measure (ICCs ≥ 0.80) for the use of locating high pressure regions and is therefore superior to taking a single reading of each sensor.

BACKGROUND

The relevance of seating research has arisen from the need to understand and solve multiple sitting related problems. For example, one such problem relates to decubitus ulcerations over bony prominences at the chair-buttock interface for wheel-chair patients. Another and distinctly different problem relates to the considerable shift to sedentary work in industrialized countries that has resulted in discomfort due to prolonged time spent in sitting (1). Given these problems, the measurement of seating pressure distribution has become increasingly important, with respect to prevention of pressure sores and promotion of comfort (2).

When evaluating effectiveness of cushions, pressure under the ischial tuberosities is the most important because the ischial tuberosities are separated from the seat by skin and fat only (3). In this study we chose a force sensing array to measure pressure under the ischial tuberosities because it has the advantage of indicating high pressure areas over the whole chair-buttock interface.

In the area of interface pressure measurement under the ischial tuberosities, only a few investigators have reported the reliability of the measurement protocol. Therefore, the primary purpose of this study was to propose and examine the inter-trial reliability of a protocol used to measure sitting pressure under the ischial tuberosities. A secondary purpose of the study was to evaluate the effect of subjects repositioning between trials on the spatial location of the ischial tuberosity pressure as measured by this protocol.

METHODOLOGY

A sample of convenience, composed of 12 healthy female volunteers over the age of 30 years was used (mean age 35.3 ± 4.2 yrs; mean weight 65.8 ± 10.6 Kg; mean height 1.65 ± 0.05 m). The VERG (Vision Engineering Research Group) interface pressure mat, used in this study, consists of a 15x15 array of force sensing resistors designed to map pressure at the buttock-chair interface. The VERG hardware can scan the entire mat array at various rates to a maximum of 3 Hz. Dynamic validity of the mat has been established (4).

Subjects were asked to sit upright in a standardized position on the testing chair, on which the pressure mat was centered. The chair was adjusted for each subject to obtain a 90° flexion angle at the knee and hip joints, respectively. The sitting position tested was upright sitting, defined as the position in which the center of gravity of the trunk is above the ischial tuberosities when the hip, knee and ankle are each at a right angle (5).

Sitting pressure distribution data was recorded every 5 seconds over a period of 30 seconds (7 readings). Subjects were then asked to stand, walk around for 1 minute, and then sit again to take

the second series of measurement. Three sitting trials were recorded.
Similar to Kernozed and Lewin (6), a customized data management program was developed to calculate the average of the maximum pressure over a 3x3 block of sensors for both the left and right sides of the mat. The program detected the 3x3 block of 9 sensors with the highest pressure on both the right and the left side of the mat (Figure 1), and calculated the mean for both sides. In order to test the reliability of the spatial measurement of the average pressure, two arbitrary points were selected [(4,1) on the left, (12,1) on the right]. The average distance from these points to the center of the 3x3 array of peak pressure (Figure 1) was calculated in order to give a single number representing the spatial measurement in the right and another for the left side.

Figure 1: The 15x15 array output in mmHg

Lt reference point (4,1) — Rt reference point (12,1) — shaded: 3x3 array of peak pressure

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	4.7	7.8	10	0	0	0	0	7.8	19	8.6	0.8	0	0
3	0	6.3	29	25	20	16	0	0	0	19	25	24	24	0	0
4	0	23	27	23	26	21	0	0	1.6	25	30	24	33	8.6	0
5	3.9	27	28	27	32	27	21	0	13	32	30	27	33	22	0
6	9.4	29	29	37	31	32	16	3.9	13	31	40	28	32	24	0
Front 7	9.4	28	37	37	42	38	22	13	28	42	36	31	29	26	0
8	0	23	36	43	59	42	32	0	29	58	50	49	37	28	0
Back 9	0	20	37	49	99	53	20	0	21	89	60	48	37	20	0
10	0	22	42	45	64	52	47	20	26	93	67	42	28	24	0
11	0	12	23	37	56	38	45	15	27	36	51	24	16	7.1	0
12	0	6.3	13	28	40	47	35	20	28	41	29	23	14	0	0
13	0	0.8	13	20	34	32	49	20	24	24	28	14	2.4	0	0
14	0	0	0	8.6	23	16	20	0	16	23	5.5	2.4	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Left — Right

Data were analyzed in StatView 4.01 Software Program, using a Macintosh Quadra800 computer. Repeated measure analysis of variance (RM-ANOVA) was used to calculate variances and p-values to test for differences between trials. Level of significance was set at $\alpha=.05$. Intraclass Correlation Coefficients (ICCs) were calculated to examine the agreement between the three sitting trials in the measurement of the average right and left peak pressure (between trial reliability). Also, ICCs were calculated to test the reliability of the spatial measurement of the mean peak pressure and to examine the effect of repositioning between trials. Throughout the study, the ICC acceptance level was set at 0.75 (7).

RESULTS

Table 1

Reliability estimates (ICC values) based on the RM-ANOVA for the mean 3x3 block and the spatial measurement of the location of the peak pressure showing that the program detects the location of the 3x3 block in a reproducible manner and that the mean peak pressures (right and left) were reliable for all combinations of trials ($p>0.05$).

Trial	Mean peak pressure		Spatial measurement	
	Right	Left	Right	Left
1,2,3	.92	.95	.90	.94
1,2	.83	.90	.80	.92
1,3	.90	.97	.87	.83
2,3	.89	.91	.88	.96

DISCUSSION

This paper describes a methodology by which pressure under the ischial tuberosities can be measured in a reproducible manner.

Most reliability studies on pressure distribution based their comparison of contact pressure at various sites on the calculated average pressure at each site (8). In the present study, the mean peak pressure, over an area of 3x3 sensors calculated from 7 readings over a period of 30 seconds, was used as the criterion measure. The choice of taking the mean of 3x3 block of sensors was made because it would give more accurate results than the use of a single peak value since the error associated with a single measurement is often greater than that for the average of several measurements (9). Of note, the ICC values for the average pressure under the ischial tuberosities in 3x3 blocks as calculated in this study compares favorably with ICCs of 0.92 reported by Kernozek and Lewin (6).

The high reliability of the spatial measurement of the 3x3 mean peak pressure indicate that repositioning the subject on the mat after each trial did not produce significant changes. Also, the reliability of the last two trials (2,3) being higher than the others could indicate that subjects were accommodating to the chair and to the test. The spatial measurement in our study was found to be reliable These results do not agree with those of Bader and Hawken (10), who found that repositioning the subject produced statistically significant changes in all pressure parameters. We believe that the discrepancy between the results of Bader and Hawken and the present study could be explained by the different protocols used as well as the differences in parameters tested.

The methodology described in this paper would be useful for researchers who are interested in left to right asymmetries in sitting pressure distribution. Furthermore, it would allow precise mapping of the location of pressure peaks. These results should be of particular interest to clinicians who need to understand how sitting pressure distribution can be reliably measured in a variety of client populations, in addition to those at risk of developing pressure ulcers.

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AN EVALUATION OF THERAPEUTIC FOAM MATTRESSES IN PRESSURE REDUCTION

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Abstract

Pressure sores are expensive, aesthetically displeasing and reduce overall quality of life. A variety of products decrease the pressure exerted on tissues at bony prominences, thus reduce the risk of pressure sore formation. Of these, foam is a clinically useful product due to its adaptability, effectiveness and low cost. Tissue interface pressures were measured on 30 subjects at four bony prominences, using the Mini Texas Interface Pressure Evaluator. This study found that the foam support surfaces distribute pressure more effectively than a standard hospital mattress. It was also noted mattresses with contouring are more effective than those without, in reducing tissue interface pressures. Finally, though not measured, a covering may alter the effectiveness of a support surface.

Statement of Problem/Purpose

According to the Veterans Administration, 50% of all quadriplegics will enter the hospital at some point due to a skin pressure related problems, and approximately one-fourth of these will prove to be fatal (1). The Department of Health in the United Kingdom estimates that 70% of pressure sores will occur during hospital stays, causing approximately 2,000 deaths a year (2).

These statistics are alarmingly high especially considering the plethora of specialty products available to both hospitals and homes. These products claim to decrease decubitus ulcers and/or pressure sores by redistributing the body's weight over a large surface. Therapeutic mattresses have shown to reduce the interface pressures at the scapula, sacrum, trochanter and heels as compared to a standard hospital mattress [(3), (4) & (5)].

It is important for health care professionals to understand the advantages and disadvantages of available products based on cost, skin integrity and life style in order to match patients to the best product. Products are generally classified by content: air-filled, liquid-filled, gel-filled and foam-filled. However, research reporting quantitative information concerning supporting surfaces and pressure relief is limited.

The purpose of this study is to investigate the effects of adjusting the contour and covering of a foam support surface to fit the differing support needs presented by the various segments of the body. Foam is the study material of choice due to its economical advantage, pressure reduction effectiveness, adaptability and availability.

Methodology

Subjects: Thirty volunteer subjects were tested by categorizing each according to body build as published in *Documenta Geigy Scientific Tables* (5).

Materials: Interface Pressure measurements were made using the Mini Texas Interface Pressure Evaluator (Mini-TIPE). The following is a description of the products tested:

Table I

Pair	Product	Mattress Characteristics	Surface Characteristics	Covering
A	one (1)	4" foam overlay	contoured	None
	two (2)	4" foam overlay	not contoured	None
B	three (3)	foam core replacement mattress	contoured	Elastomer coated
	four (4)	foam core replacement mattress	not contoured	Elastomer coated
C	five (5)	foam core replacement mattress	contoured	Staphcheck
	six (6)	foam core replacement mattress	not contoured	Staphcheck
D	seven (7)	modular replacement mattress	contoured	Urethane backed nylon
	eight (8)	modular replacement mattress	not contoured	Urethane backed nylon

Note: the odd numbered mattresses are zoned and that the even numbered mattresses are not zoned.

Mattresses: Four sets of paired products were used in this study. Each paired set of support surfaces consisted of a product that is anatomically contoured and the same product without a contoured surface. The mechanical characteristics of each were tested according to the product's density, stiffness and thickness.
Positions: In each case, the position of the subject for both supine and side lying was standardized to reduce the variations in interface pressure that can occur as the subject changes positions. *Procedures:* The mattress was placed on a standard hospital bed frame. The Mini-TIPE pressure transducer pad was placed on the mattress under a bony prominence as the subject lied supine or side-lying. Several measurements were obtained at each prominence and the average was reported.

Results/Discussion

Table II displays the average peak pressure under each of the bony areas, the standard deviation associated with each reading and the results of a two-tailed T-test that compared the effects of contoured mattresses, in relation to tissue interface pressure. Since the performance of a product can be influenced by the physique of the subject, the data has been stratified by body type. As compared to the standard hospital mattress, a decrease in the interface pressure of the tested mattresses results in increased effectiveness of the replacement support in reducing pressure and therefore decreasing pressure sore formation. Further, in each product pair, a contoured support surface generated a lower interface pressure than the non-contoured surface.

For paired product A, a contoured surface significantly ($p<0.01$) reduced the interface pressure at the heels for all three body types and at the trochanters for the thin and average body type. No significant difference in pressure was noted at the trochanteric area in the large body build habitues, nor at the scapular or sacral areas in all three body builds. It would seem that a contoured foam overlay is appropriate for all body builds who lay supine and experience breakdown in the heel area as well as patients who are thin or average in size and prefer side-lying.

The second group of paired products B yielded a significant difference in reducing the tissue interface pressure at the trochanters for a thin built person ($p<0.05$) as well as the sacral and trochanteric areas of an averaged sized person ($p<0.01$). For a large body build, no statistical significance was noted at any bony prominence with measured pressures at the sacrum and trochanter being almost equal. From this data, the contoured replacement mattress would only provide marginal benefit for a thin or averaged sized individual who prefers side-lying but no benefit to a larger person. It should be noted however, that the recorded pressure for both products is still dramatically lower as compared to the standard hospital mattress, though not as low as these measured in group A.

Testing of paired product C, yielded pressure measurements similar to those recorded for paired product B. Measurements between this contoured and non-contoured foam core replacement mattress yielded statistically significant difference ($p<0.01$ and $p<0.05$) for all builds at all bony prominences, except the scapular areas of a thin and large builds. A contoured surface was shown again to reduce interface pressures of thin and large persons at the trochanteric, sacral and heel areas; with the average sized individual, statistical significance ($p<0.05$) was found at all bony prominences. Based on these results, a contoured product is highly effective in reducing tissue interface pressures.

In paired product D, the contoured modular replacement mattress pressure readings indicate that this mattress is more effective in reducing the tissue interface pressure at the heels for all body builds to the 0.01 alpha level. The contoured mattress was also effective in reducing the pressure at the trochanteric area of the thin and large body build ($p<0.01$) and the scapular area of the averaged sized adult ($p<0.05$). Similar to product 1, product 7 would be most effective for individuals with pre-existing compromise of heel skin integrity who preferred to lie supine or on their side.

Table II

Prominence	Std. Mat	Prod 1	Prod 2	T-test	Prod 3	Prod 4	T-test	Prod 5	Prod 6	T-test	Prod 7	Prod 8	T-test
Thin Build													
Scapula	27+/-14	17+/-5	17+/-4	0	22+/-4	22+/-6	0	18+/-2	19+/-3	1.05	17+/-2	17+/-2	0
Sacrum	32+/-13	21+/-6	20+/-7	0.45	25+/-5	26+/-6	0.53	22+/-3	26+/-4	3.15 **	25+/-4	26+/-4	0.79
Trochanter	77+/-28	32+/-4	47+/-12	3.95 **	45+/-10	51+/-7	2.70 *	38+/-7	46+/-5	5.06 **	40+/-9	46+/-5	3.80 **
Heels	49+/-18	23+/-7	39+/-14	3.61 **	43+/-8	43+/-12	0	28+/-7	43+/-12	3.95 **	28+/-8	43+/-12	3.95 **
Avg Build													
Scapula	29+/-17	17+/-3	16+/-4	0.9	20+/-5	21+/-5	0.72	19+/-4	21+/-3	2.41 *	19+/-3	21+/-3	2.41 *
Sacrum	29+/-5	23+/-5	25+/-5	1.44	25+/-8	29+/-4	3.60 **	26+/-5	29+/-4	2.70 *	27+/-5	29+/-4	1.8
Trochanter	67+/-20	38+/-6	50+/-7	6.19 **	49+/-9	57+/-5	5.76 **	44+/-9	49+/-8	2.25 *	49+/-7	49+/-8	0
Heels	47+/-4	22+/-6	35+/-10	4.69 **	42+/-7	44+/-7	1.03	41+/-7	47+/-8	2.70 *	34+/-7	47+/-8	5.86 **
Large Build													
Scapula	31+/-3	21+/-3	21+/-4	0	22+/-7	25+/-5	1.59	22+/-4	20+/-3	1.77	23+/-3	20+/-3	2.65 *
Sacrum	40+/-8	26+/-6	26+/-7	0	29+/-3	29+/-5	0	27+/-5	30+/-3	2.65 **	29+/-5	30+/-3	0.88
Trochanter	81+/-19	42+/-8	52+/-14	1.89	52+/-9	52+/-6	0	51+/-5	55+/-2	5.33 **	48+/-5	55+/-2	9.30 **
Heels	71+/-29	21+/-7	44+/-9	6.76 **	49+/-7	52+/-9	0.88	40+/-4	52+/-9	3.53 **	30+/-6	52+/-9	3.53 **

Conclusions

Based on the results of the testing performed in this study, each of the products tested, whether contoured or not contoured, yielded dramatically lower tissue interface pressures at all four bony prominences tested and with all body builds as compared to the standard hospital mattress. Initial data suggests that paired product A yielded the lowest tissue interface measurements as compared to the other three products tested. This however, may be a result of the detrimental effects of the type of covering used on the remainder of the paired products tested, as the internal composition and specifications of each product was similar. Paired product B had an elastomer coating; paired product C contained a staphcheck covering and paired product D utilized a urethane backed nylon cover. Paired product A was the only product tested without a covering. These results remind the healthcare market to be mindful of the effects of a cover in masking the effectiveness of a pressure reducing or relieving mattress and potentially contributing to increases in tissue interface pressure and therefore pressure sores. Finally, contoured products or those containing zoned stiffness, tend to generate a lower tissue interface pressure, again making them less likely to contribute to skin breakdown.

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A PHANTOM FOR THE EVALUATION OF PRESSURE RELIEF SURFACES

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ABSTRACT

A phantom has been developed for the evaluation of pressure relief surfaces. Comparison of interface pressure maps with a healthy volunteer indicates that the phantom represents realistic physiological loading conditions, with greatly enhanced repeatability.

BACKGROUND

Pressure ulcers are a major problem world wide believed to affect over 5 % of all hospital in-patients, and countless others in the community at large. The care of patients with pressure ulcers has been estimated to be costing the NHS between £180 million and £321 million per annum (1).

An efficient way to prevent or manage ulcers is to provide specialised beds, mattresses, chairs, cushions, which distribute the pressure more evenly over the soft tissues. The relative merits of products and the basis of the claims made by manufacturers are unknown, as there is no generally recognised standard protocol or method for the evaluation of the efficacy of pressure relief surfaces.

Because of intractable logistic difficulties, as yet only a small number of randomised controlled trials (RCT's) have been conducted for the effectiveness of pressure relief surfaces, and the results of these have been inconclusive (2). Where they have been reliable statistically, there were perhaps very big actual differences in performance between the products used in the trial (3), (4). RCT's may also be confounded by their lengthy duration - typically a well conducted trial lasts 3-5 years (5). In this time the support systems in the trial may have become obsolete and newer models introduced.

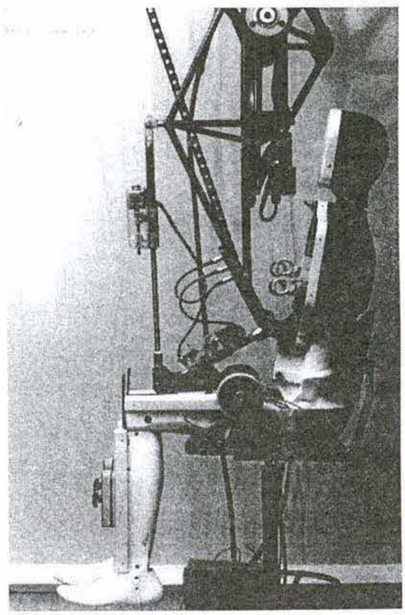


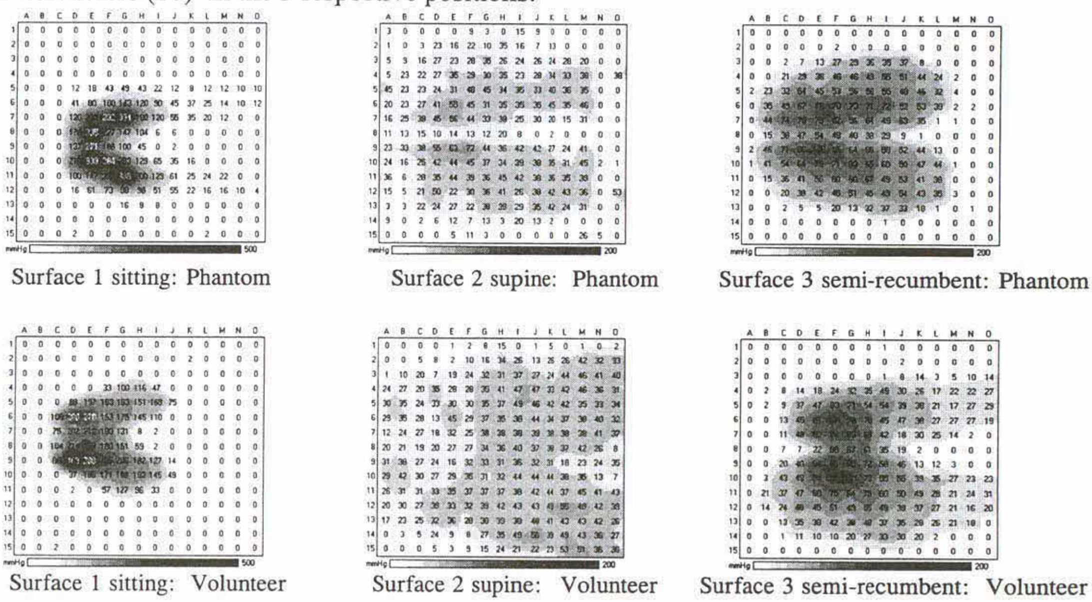
Figure 1: the phantom

The use of pressure measurement on live human subjects to assess efficacy introduces non-repeatability and variability in results, which impugn statistical significance (6). Mechanical testing without human volunteers provides faster evaluations of support systems, with improved precision and repeatability (7), (8), (12). The validity of tests using of mechanical indentors, however, has been shown to be highly dependant on indentor geometry (9) and physical properties (10), and the faithfulness of these quantities to the range of human physique.

THE PHANTOM

An instrumented articulated anthropometric phantom (Patent IPC 94928968.0) has been developed (11), with simulated soft body "tissues" in the gluteal and sacral areas. The weight of the phantom can be adjusted between 50kg and 90kg and can be precisely and repeatably applied to a surface in a predetermined supine, semi-recumbent, or sitting position, using a ceiling-mounted guidance system (Figure 1).

The phantom consists of an articulated body-shell, segmented into head, torso, upper legs (joined) and lower legs (13). Each discrete segment has an adjustable mass at its centre of gravity, to model different body-weights and distributions (14). Interchangeable pelvic units represent the supine, semi-recumbent, and sitting positions. Each consists of an articulated polyester pelvis and femurs, with an additional web to simulate the tissue confining effects of the ligaments and deep fascia. The soft tissues of the pelvic region are a silicone polymer compound with the same mean instantaneous static hardness value as the buttock tissues of 19 volunteers (mean age 68.2 years, s.d 3 years), as measured using a specially designed durometer (10). The silicone compound was moulded in a CNC-generated mould representing the shape derived from numerical topography data acquired by laser scanning the same volunteers (10) in the 3 respective positions.



Surface 1 sitting: Phantom — Surface 2 supine: Phantom — Surface 3 semi-recumbent: Phantom

Surface 1 sitting: Volunteer — Surface 2 supine: Volunteer — Surface 3 semi-recumbent: Volunteer

Figure 2: pressure maps paired for surface and orientation

RESEARCH QUESTION

The aim of this study is to compare the loading conditions created by the phantom on a range of pressure relief surfaces with those of a healthy volunteer on the same surfaces.

METHOD

The phantom was configured to 90kg, and applied to a variety of surfaces ranging in softness from a plywood board (surface 1), to a Low-Air-Loss Bed (surface 2), with a number of intermediate surfaces. The phantom was applied in the supine, semi-recumbent, or sitting positions as appropriate to the surface. Interface pressure in the buttocks region was mapped using an FSA (Force Sensing Array) system (VERG, Winnipeg, MB). Pressure maps were also made of a healthy volunteer weighing 86kg on the same surfaces. Sample traces for phantom and volunteer are shown in figure 2, paired for support surface and orientation.

CONCLUSIONS

The comparison of interface pressure maps give confidence that the phantom simulates realistic loading conditions of at each angle of flexion, and on each surface. Additional findings were that the phantom gave much more repeatable conditions than those of the volunteer. This feature is essential for statistical selectivity, and so the use of the phantom provides potential the creation of International Standards for the evaluation of pressure relief.

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RELIABILITY OF THE IN VIVO TEST PROTOCOL FOR MEASURING INDENTATION PROPERTIES OF BUTTOCK SOFT TISSUE

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ABSTRACT

In vivo indentation properties of buttock soft tissue were evaluated using the Computer Automated Seat System (CASS) and quasi-linear viscoelastic (QLV) modeling. Two non-disabled subjects, age 20 and 23, were tested. R^2 for curve fitting of the QLV model parameters to experimental data were greater than 0.97. The ratios of standard deviation to mean for all four QLV parameters were less than 27%. The time-dependent relaxation material parameter, α, from the two subjects was similar. The intraclass correlation coefficient (ICC) for the other three parameters were larger than 0.72. The results demonstrated the reliably and repeatability of our in vivo buttock soft tissue assessment process using the CASS and associated protocol.

INTRODUCTION

People with SCI are at the high risk of tissue breakdown. Prolonged sitting with excessively high pressure and lack of sensation often leads to the tissue ischemia and breakdown over the ischial tuberosity and sacralcoccygeal region [1]. Assessment of the tissue's response to loading may help to predict risk of pressure ulcer development.

Soft tissues have viscoelastic, anisotropic, and incompressible properties [2]. Fung proposed the quasi-linear viscoelastic model (QLV) to assess tissue biomechanical loading characteristics [3]. Hayes developed a mathematical model for indentation tests of articular cartilage using linear, elastic theory [4]. Based on the Hayes indentation solution for a plane-ended cylindrical indentor, Zheng devised an instantaneous Young's modulus of soft tissue in Fung's QLV form. The extended equation was used to model the viscoelastic properties of lower limb soft tissue during indentation testing [5].

This paper describes the development of a protocol for in vivo determination of QLV parameters of buttock soft tissues using the CASS and Zheng derived solution. The repeatability of determining QLV parameters acquired by the proposed protocol is evaluated in this paper.

METHOD

<u>Instrumentation</u> A CASS [6, 7] comprises an 11 by 12 array of support elements that form an adjustable seat support surface. A pressure transducer is fixed in the center of a swiveling head on each sensor in the 3 by 3 sub-array over the right ischial tuberosity. Four ultrasonic transducers are evenly distributed around the pressure transducer. The swiveling head can freely tilt and rotate so that the pressure and ultrasonic transducers are oriented in a direction normal to the tissue surface. The vertical force applied to the sensor is measured using a force transducer located in the bottom of the sensor body. Hardware and software were developed to monitor ultrasonic echoes. Using an automated echo tracking technique, tissue thickness, interface pressure, tilt angle and force are recorded simultaneously during dynamic loading conditions.

<u>Test protocol</u> Two non-disabled male subjects (ages: 20 and 23, Mass: 68 kg and 81.6 kg, Height: 183 cm and 174 cm) with healthy tissues were used for this study. Each subject was seated on the CASS and positioned the test site (4-cm in front of the ischial tuberosity) was above one of the sensors contained in the 3 by 3 sensor sub-array. Posture was adjusted until the subject was in a comfortable position and ultrasound echoes could be monitored. Belts and pads

helped to stabilize the shoulders, hip, and knee. Tissue preconditioning was performed with the sensor over the test site. Cycles of indentation and recovery movements for 3 minutes (19 cycles) at 1.058 mm per second velocity were conducted. The indentation range was less than 20% of initial thickness of the bulk soft tissue layer. Immediately after the preconditioning, three indentation tests were performed. The time between trials was less than 20 seconds. The sensor moved through indentation, hold (5 minutes) and recovery phases at 1.058 mm/sec. The maximum indentation range was less than 20% of initial thickness of bulk tissue and maximum indentation force generated less than 13.5 N. The interface pressure, indentation force, sensor head tilt angle, and thickness of buttock soft tissue layers (fat, muscle, and bulk tissue) were recorded.

Curve fitting and viscoelastic parameter extraction According to Zheng's solution, the indentation force response can be described as follows,

$$P(t) = \int_{-\infty}^{t} G(t-\zeta)\frac{\partial P^{(e)}(u(\zeta))}{\partial u(\zeta)}\frac{\partial u(\zeta)}{\partial \zeta}d\zeta \qquad (1)$$

The reduced relaxation function, G(t), is

$$G(t) = 1-\alpha+\alpha e^{-t/\tau} \qquad (2)$$

The elastic response, $P^{(e)}(u)$, is defined as,

$$P^{(e)}(u) = \frac{2ah}{1-\nu^2}uk(h,u)E^{(e)}(u) \qquad (3)$$

and, the elastic indentation force response is defined as,

$$E^{(e)}(u) = E_0 + E_1 u(t) \qquad (4)$$

where, α, τ, E_0, and E_1 represent the reduced relaxation parameter, time constant, initial modulus, and nonlinear modulus respectively, a is the radius of the indentor, ν is Poisson's ratio, k(h, u) is a scaling factor that is a function of a/(h(1-u)) and can be obtained from the table given by Hayes et al. [4], and u (t) is the ratio of the deformation, w, to the initial thickness of the tissue layer, h.

RESULTS

A typical data set is shown in Fig.1. To model reduced relaxation parameters, α and τ, force response data in the hold phase was normalized to using the peak force (Fig.2). t_0 was set as the beginning of the hold phase and t_∞ was set as $t_0 + 300s$. E_0 and E_1 were obtained from the indentation phase (Fig.3). The results are summarized in table 1.

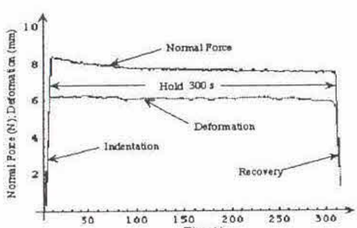

Fig.1 Loading response data with time for a typical trial

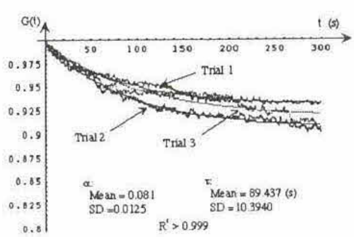

Fig.2 Curve fitting reduced relaxation to a typical experimental data

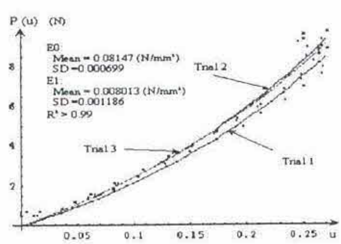

Fig.3 Curve fitting elastic response to a typical experimental data

Table 1: Load-Indentation Testing and Curve Fitting Results

	Subject 1				Subject2			
Parameters	α	τ (s)	E_0 (N/mm²)	E_1 (N/mm²)	α	τ (s)	E_0 (N/mm²)	E_1 (N/mm²)
Mean	0.081	89.44	0.00375	0.04777	0.087	64.06	0.00815	0.00801
SD/Mean %	15.47	11.62	12.81	15.13	22.64	26.77	6.08	16.26
R^2 for curve fitting	>0.93		>0.87		>0.92		>0.97	
ICC_α: — ;	ICC_τ: 0.726 ;		ICC_{E0}: 0.9675 ;		ICC_{E1}: 0.9212			

Note: Repeated values for each subject are taken over 3 trials.

DISCUSSION AND CONCLUSIONS

It was very important that subject remains still and quiet during data acquisition. Any movement had adverse effects on the data. The time-dependent material parameter, α, from two subjects were similar. The intraclass correlation coefficient (ICC) for the time constant, τ, was 0.726, for the initial modulus, E_0, was 0.9675, and for the nonlinear modulus, E_1, was 0.9212. Repeatable results indicated that when using the CASS and QLV modeling, the proposed test protocol can provide reliable data to determine the in vivo biomechanical properties of buttock soft tissues. Various factors including indentation speed, tissue compression ratio, indentation load, interval time between tests, hold time, precondition time, muscle tone, site, posture and composition of soft tissue influence QLV model parameters and will be explored in subsequent studies.

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ARE COMMERCIAL SEAT CUSHIONS EFFICACIOUS IN PREVENTING PRESSURE ULCERS IN THE AT-RISK ELDERLY NURSING HOME POPULATION?

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ABSTRACT

This study developed and tested a protocol for use in a multi-center, clinical trial to evaluate the efficacy of pressure-reducing cushions in the at-risk, elderly nursing home population, a population which remains underserved. Thirty-two at-risk, elderly resident wheelchair users completed the study. All subjects received individually prescribed wheelchairs. Subjects were randomized to foam or pressure-reducing cushion (PRC) groups. PRC selection was based on subject seating needs and interface pressure-mapping which was obtained for both groups. Sitting time, risk and skin changes were monitored. The primary endpoint was a seating-surface pressure ulcer (PU). Interface pressure was a significant predictor of PU incidence. No significant difference ($p>.05$) was found for PU incidence. Failure to reach statistical significance was attributed to low power (0.21), a difference in sitting time, and an inadequate operational definition for a sitting-induced PU. Future plans for a multi-center clinical trial are in progress.

BACKGROUND

Valid estimates of the prevalence and incidence of sitting-induced pressure ulcers in the immobile, elderly nursing home (NH) population are elusive. They are generally flawed due to inconsistency in defining pressure ulcer stages and the fact that Stage I pressure ulcers are unreliably assessed. However, the best estimates to date report the prevalence of all pressure ulcers among NH residents to be in the range of 7%-28% (1, 2). Two of the most common sites include over the ischial tuberosities (15%) and the sacrum or coccyx (36%) (2). If the majority of pressure ulcers over the ischial tuberosities and a small percentage of sacral/coccygeal ulcers are incurred from excessive pressure in sitting, then pressure reducing seating interventions have the potential to prevent at least 15% of these ulcers.

Assessments of pressure ulcer risk indicate that individuals who lack functional mobility are at greatest risk for ulcer development (1). The United States NH population includes an estimated 600,000 immobile, elderly wheelchair users (3) who are generally not evaluated for seating and positioning needs. Although commercial cushions are available, reimbursement is not routinely available for seating evaluations or cushions due largely to the fact that the efficacy and cost effectiveness of these interventions has not been sufficiently demonstrated in this population.

RESEARCH QUESTION

The primary goal of this study was to develop and test a protocol for a multi-center randomized clinical trial to investigate the efficacy of pressure reducing seat cushions in preventing pressure ulcers in the at-risk NH population.

METHODS

Over a one-year period, thirty-two subjects who were cumulatively recruited from two local skilled nursing facilities completed the study. Inclusion criteria were: (1) 65 years or older, (2) a

Braden score of ≤ 18, (3) a combined Braden Activity and Mobility Subscale score of ≤5, (4) absence of sitting-surface pressure ulcers, (5) a tolerance for total daily wheelchair sitting time of ≥6 hours and (6) having seating needs that could be accommodated by the ETAC Twin wheelchair including a body weight of ≤250 lbs. Treatment began with the seating assessment performed by a specialist who was also responsible for ongoing evaluation and wheelchair adjustment. A new, individually modified ETAC Twin wheelchair was issued to each subject. The provision of an individualized seating system for each subject was deemed necessary to keep the effects of the cushions independent of the confounding effects of an improperly-fitted wheelchair.

Subjects were randomized to either a foam (FOAM) or pressure-reducing cushion (PRC) group. The FOAM group received a generic 3 inch convoluted-foam cushion, fitted incontinence cover and solid seat insert. The PRC group received a fitted incontinence cover and a commercial cushion selected from a group of cushions designed specifically to improve tissue tolerance in sitting by providing more surface area and/or reducing peak pressure near the ischial tuberosities, sacrum and coccyx areas of the seating surface. As part of the seating evaluation, interface pressure measurements were recorded for all subjects while on their seat cushions using a Force Sensing Array pressure-mapping device (Vistamed, Manitoba, Canada). The selection of a particular cushion for subject use was based on subject specific clinical criteria including interface pressure measurements.

Skin and risk assessments were performed weekly by research team staff from the time of enrollment in the study until study endpoint defined as: first incidence of a pressure ulcer, discharge from the facility, death, or the study end-date (July 1999). Skin reaction was classified using the National Pressure Ulcer Advisory Panel (NPUAP) staging method (4). The Braden Scale for predicting pressure ulcer risk was used in risk assessment. Seating re-assessments occurred at the nursing facility one week (± 1 day) and as needed following modification of any wheelchair.

All statistical analyses were performed at the 0.05 level of significance. An independent t-test was used to examine differences between the means for FOAM and PRC groups as well as the Pressure Ulcer (PU) and Non-Pressure Ulcer (NPU) groups. The Chi square test was used to examine the expected/observed frequencies of the same groups for categorical data. Power analyses were completed for the current study data and also for estimating the sample size needed for a multi-center, randomized clinical trial with an effect size of 0.3, power of 0.8 and α=0.05.

RESULTS

The characteristics of the FOAM and PRC groups did not differ significantly for age, sex initial Braden Score, or diagnoses. In addition, no differences were found between the groups after further stratification of the subjects into either a higher-risk category based on the initial Braden score (8-13) or a lower-risk category (14-18).

The FOAM group failed to meet the minimum required sitting-time of six hours per day significantly more often than the PRC group. The clinical determination of postural asymmetries and peak interface pressure measurement were both significantly more predictive of pressure ulcer site for the FOAM group than for the PRC group. No significant difference was found between the groups for pressure ulcer incidence. A total of 16 subjects developed pressure ulcers (6 out of 15 in the PRC group and 10 out of 17 in the FOAM group). No significant difference was found between the groups for either the ratio of total days subjects were rated as at-risk (≤18 Braden score) to total study days, or for each group's total days to reach endpoint.

Data analyses of the PU and NPU groups were also performed. A significant difference was found between the groups for initial peak interface pressure. The mean peak pressure for the subjects with PUs was 115 mmHg (sd= 44.6 mmHg) and 78 mmHg (sd= 21.7 mmHg) in the NPU group. No significant group differences were demonstrated for initial Braden scores, stratified Braden scores, sitting-time variances, or ratios of days at-risk to total study days.

DISCUSSION

Fifty-percent of the subjects in this pilot study developed pressure ulcers which exceeded our expectations based on previous estimates. Higher interface pressures are associated with higher incidence of sitting induced pressure ulcers in this population. These results support the use of pressure measurements as an aid in determining pressure ulcer risk. The difference in sitting-time observed for the FOAM group may have extended the time that a number of higher risk subjects in the FOAM group remained PU-free. A device to monitor actual sitting time could be useful in future studies. For the FOAM group, the site of pressure ulcer development was consistent with that expected from the postural asymmetries identified during the clinical evaluation and from the location of the peak interface pressure. This difference might be explained by PUs in the PRC group *not* being induced by sitting. In fact, 3 of the 6 PUs that occurred in the PRC group were due to shearing but according to study definitions were classified as PUs. Failure to reach statistical significance for pressure ulcer incidence was likely due to an inadequate operational definition for a seating-induced PU, insufficient power (0.21), and group differences in sitting-time. This study demonstrates the feasibility of a multi-center, randomized clinical trial and, with modifications, projects a modest sample size (54 subjects/group). Plans for the trial are in progress.

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A TOOL FOR DETERMINING THE HEAT TRANSFER AND WATER VAPOUR PERMEABILITY OF MATTRESSES AND WHEELCHAIR CUSHIONS

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ABSTRACT

Development of a tool for the simultaneous measurement of the thermodynamic and water vapour dissipating properties of support surfaces with complex shapes such as wheelchair cushions, giving important information on the ability to maintain a normal physiological microclimate.

BACKGROUND

The formation of pressure ulcers can be exacerbated by a breakdown in the integrity of the patient's skin caused by poor maintenance of the skin microclimate. Mattresses and wheelchair cushions play an important role in the dissipation of heat and moisture away from the skin/support interface, necessary to maintain the physiological skin microclimate. If these mechanisms are impeded then the skin temperature rises and moisture accumulates.

Over hydration of the skin from the accumulation of moisture can lead to an increase in maceration and excoriation (1) and an increased coefficient of friction between the patient and the support surface. This, when coupled with excessive pressure can cause blistering and superficial erosions when the patient is slid on a bed sheet (2). Overheating or cooling of the skin changes the metabolic demands of the cells, further endangering ischaemic areas (3).

Using clinical measurements to compare support surfaces based on their ability to maintain a normal skin microclimate is difficult due to the wide variation in values between subjects (4) and the large numbers required to produce significant differences (5). Clinical assessments on a range of support surfaces show the relative humidity under the buttocks varies between 40 and 100% and the temperature under the ischial tuberosities varies between 30°C and body temperature (6,7,8).

Laboratory tests that do not use human subjects are objective and can produce precisely controlled conditions (4,9). Methods for assessing the thermal properties of textiles (10,11) are available but are unsuitable for assessing complete support systems that are composite structures and can have complex shapes; the performance of individual components will not necessarily indicate total performance. Other tests for assessing complete support surfaces (4,6) do not measure insensible heat losses, which can be significant, and do not assess the test specimen when it is compressed and stretched under load, i.e. when a patient is lying on a mattress for example.

In this paper is reported a tool that has been developed for the simultaneous measurement of the heat and water vapour dissipating properties of complete mattress systems (12) and its further development for assessing wheelchair cushions.

RESEARCH QUESTION

This paper describes further development of a tool for the simultaneous measurement of the thermodynamic and water vapour dissipating properties of support surfaces with complex shapes such as wheelchair cushions, loaded and unloaded.

EQUIPMENT

The principle involves the generation of an atmosphere next to the support surface that can be controlled with respect to temperature and humidity and then measuring the heat and water vapour transfer from this atmosphere through the support surface. The tool [Heat and Water Vapour Transfer System (HWVTS)] consists of two main components, a measurement block (MB) and its thermal guard (TG) separated by an air gap (Figure 1). These are made of aluminium alloy which are heated and maintained at set point temperatures (i.e. body core temperature). Distilled water drains from a reservoir into a recess milled in MB. A waterproof/water vapour permeable membrane and perforated aluminium plate sandwich is placed over the recess and made water vapour tight with the MB body. The waterproof/water vapour permeable microporous membrane has permeability very much greater than the permeability of the support surface. Water is fed to the MB through a silicon tube that passes through the wall of TG so that the water may be brought up to set point temperature before reaching MB. A layer of oil prevents evaporation from the top surface of the water reservoir.

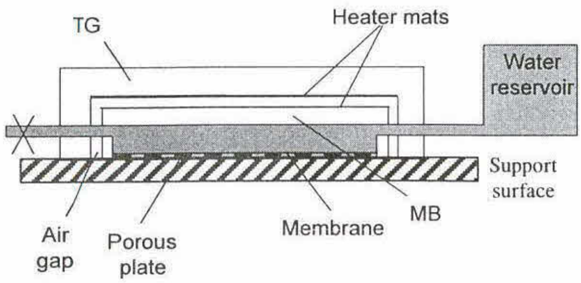

Figure 1 Heat and water vapour transfer system

The whole assembly lies with the MB resting on the support surface. The TG is maintained at the same set point temperature as MB in order to limit heat losses from MB to the atmosphere. The thermodynamic properties of the support surface are calculated from measurements of the heat power required in maintaining MB at set point temperature. Moisture dissipating properties are determined from measurements of the water loss from the reservoir.

ASSESSMENT OF MATTRESS SYSTEMS

The device represents the area of the buttocks. Results from testing mattress systems demonstrated good inter and intra test reproducibility and selectivity, exhibiting very significant differences in the heat and water vapour transfer rates between the support surfaces tested (12).

This showed Low Air Loss Bed Systems (LALBS) have very high heat and water vapour transfer rates that are in excess of physiological losses (up to $244 W/m^2$ heat loss and $>2400 g/m^2 day$ water loss) that can occur during hard work or fever. Foam mattress types with waterproof/water vapour permeable covers have much lower heat transfer rates which are less than the normal physiological resting heat losses and the temperature at the body/support interface can reach near body core temperature. They also have water vapour permeabilities that would dissipate physiological resting losses but not sweating rates.

The results demonstrate how foam limits heat transfer and the cover is the rate limiting factor for water vapour transfer. The resistance to insensible heat loss through the covers also limits heat transfer. However, measuring the permeability of the cover or foam independently does not necessarily indicate the overall performance of the support surface.

FURTHER DEVELOPMENT FOR ASSESSING WHEELCHAIR CUSHIONS

It is important that advances in support surface construction for the purpose of pressure ulcer prevention and management improve the thermodynamic and moisture dissipating properties without destroying the mechanical properties, which can be altered by heat and moisture. It is thus important to assess the thermal properties of complex support surfaces during mechanical deformation. A further modification of the mattress tool for assessing more complex shapes such as wheelchair cushions under load is shown in Figure 2. These buttocks are made of high thermal resistant material

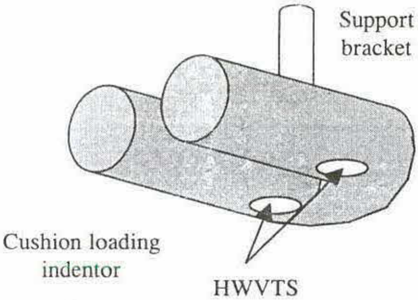

Figure 2 Cushion loading indentor with integral heat and water vapour transfer measurement systems.

and may be used as a Cushion Loading Indentor (CLI) for the simultaneous measurement of the mechanical, thermodynamic and water vapour dissipating properties of the cushion. In this example, the HWVTS units based on the mattress device have been scaled down and positioned in the area of the ischial tuberosities.

As part of the ISO initiative on wheelchair standards and Tissue Integrity Management Devices this method has been proposed for consideration as a test for heat and water vapour dissipation of wheelchair cushions.

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EFFECTIVE YOUNG'S MODULUS OF BUTTOCKS SOFT TISSUE

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ABSTRACT
Characterization of the intrinsic mechanical properties of soft tissue is essential to the study of tissue loading and pressure ulcer etiology. To this end, a method was developed to determine the Young's Modulus for the soft tissue of the buttocks. Young's Modulus was determined through a linear regression of force deformation data taken from the buttocks of an able-bodied male subject seated on the Computer Aided Seating System (CASS) [1]. In this study, the fat layer of the soft tissue was examined.

BACKGROUND
25% of the 200,000 spinal cord injured patients in the United States develop pressure ulcers each year [2]. Pressure ulcers are not only a physical and emotional burden on the injured, but also result in high medical costs. An understanding of the mechanical response of the tissue to external pressure is necessary to understand the mechanisms leading to pressure ulcers. Such mechanisms cannot be obtained without a clear understanding of the more basic mechanical properties of the tissue.

This study examines the response of buttocks tissue to an indention to characterize the effective Young's Modulus of the tissue. The main components of the buttocks tissue are fat and muscle layers. This study examines the layer closest to the skin, the fat layer.

METHODOLOGY
A flat-ended, cylindrical indenter containing force, pressure, tilt, and ultrasonic transducers was used to obtain data. The CASS, shown in Fig. 1, is an array of such sensors [1]. For this experiment, only one indenter was active. The subject was placed on the CASS with the active element 4 cm distal to the ischial tuberosity and centered under the femur. Prior to measurement, the site was preconditioned with cyclic loading for 3 minutes. Indention depth was 20% of the bulk tissue thickness, and tissue layer deformations were continuously monitored during testing using ultrasound echo tracking techniques. The indention and rate were controlled by an automated seating system to assure repeatability. The theoretical development of the characteristics of a plane-ended cylindrical indenter on an elastic layer over a rigid half-space has been previously presented by Hayes [3]. In this study, however, the reflecting surface analogous to Hayes' rigid half-space is neither infinite nor flat, therefore the tissue thickness, and hence the Young's Modulus, can only be considered effective mechanical

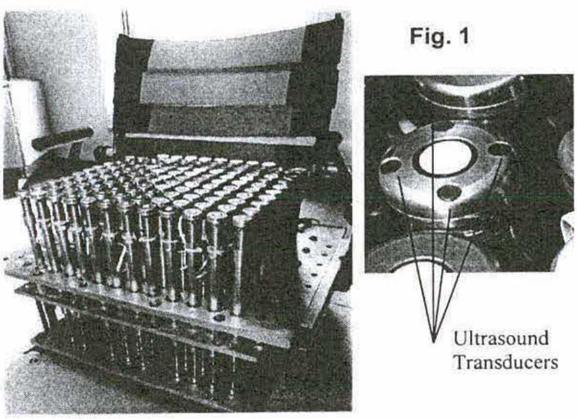

Fig. 1

properties. In a similar experiment exploring the elastic properties of lower limb soft tissue, Zheng and Mak [4] defined the effective Young's Modulus, E, as

$$E = \frac{(1-\nu^2)}{2a\kappa(\nu, a/h)} \frac{P}{w} \quad \text{(A)}$$

In (A), h is the initial fat tissue thickness, κ is a scaling factor that accounts for the finite thickness of the elastic tissue, P is the applied force, and w is the tissue deformation. κ is a function of Poisson's ratio, υ, of the tissue and the indenter's aspect ratio, a/h, where a is the radius of the indenter. Poisson's ratio was taken to be 0.45 [4]. Since a is known to be 16.825 mm, and υ is 0.45, κ can be reduced to a function dependent solely on the initial fat tissue thickness h. The new scaling factor, $K(h)$, allows (A) to be reduce to the following form (B).

$$E = \frac{1}{\mathrm{K}(h)} \frac{P}{w} \quad \text{(B)}$$

Hayes' $\kappa(\upsilon, a/h)$ results [3] can be plotted as $K(h)$ with respect to h, shown below in Fig. 2 and Table 1. This allows a scaling factor to be determined for any initial thickness with a given Poisson's ratio.

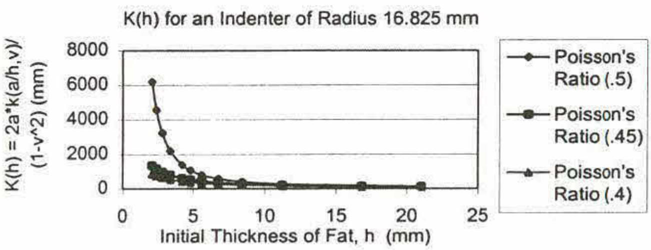

Fig. 2

Trial	h (mm)	K(h) (mm)
1	14.518	157.12
2	13.858	164.84
3	13.468	169.39
4	13.648	167.29

Table 1

RESULTS

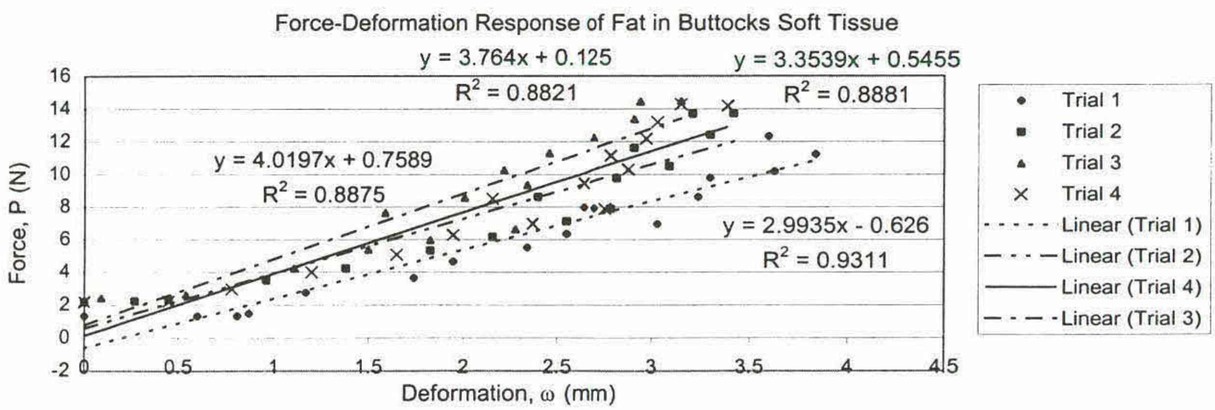

Fig. 3

Force (*P*) vs. Deformation (*w*) is shown in Fig. 3. Linear regression was used to determine the *P/w* ratio for Equation B. The effective Young's Modulus, E, for each trial is shown in Table 2 below.

DISCUSSION

Trial	h (mm)	P/ω (N/mm)	E (kPa)
1	14.518	2.994	19.06
2	13.858	3.354	20.35
3	13.468	4.020	23.70
4	13.648	3.764	23.70

Table 2

The values for the effective Young's Modulus for fat tissue calculated from the four trials ranged from 19.06 kPa to 23.7 kPa. This range of values is not unexpected, as similar ranges have been reported for the effective bulk tissue elastic modulus in studies focusing on the lower limbs [4]. The modulus values can be influenced by posture, site location, orientation of the sensor to the underlying bony structure, shape of the bony surface, muscle tension, indenter radius, morphology (initial tissue thickness), and sex. The effects of these influences on the lower leg bulk tissue elastic properties have been examined by Zheng and Mak [5]. Similar analysis of the bulk tissue constituents of buttocks soft tissue is planned for the future. Further studies to examine the influence of the effects of nonlinearity and the viscoelasticity have also been proposed. The goal of these studies will be to further quantify the viscoelastic properties of the constituent tissues of buttocks, primarily fat and muscle. If the relationship of the mechanical properties of each component to the overall mechanical properties of the soft tissue can be determined, then differences in properties between uninjured and spinal cord injured populations can be explored. The influence of each constituent on the overall bulk elastic properties will be examined in an effort to develop a method for predicting pressure ulcer risk from the mechanical response of the soft tissue.

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PHYSIOLOGIC COMPARISON OF YAMAHA JWII POWER ASSISTED AND TRADITIONAL MANUAL WHEELCHAIR PROPULSION

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ABSTRACT:

For people having difficulties with propulsion traditional electric powered wheelchairs are often neither desired nor necessary. Power assisted manual wheelchairs were developed as a solution. In order to compare the metabolic demand of traditional and power assisted propulsion, random order clinical trials were performed. Physiologic characteristics were recorded while ten subjects propelled with and without the Yamaha JWII power assisted hubs on a dynamometer with selected speeds and resistances. Significantly lower ($p<0.05$) values were found in both oxygen ventilation and heart rate when propelling the JWII. The significantly reduced physiologic demand of power assisted wheelchair propulsion facilitates longer maintenance of higher speed.

BACKGROUND

People with various physical abilities use manual wheelchairs. When these individuals get upper extremity injuries[1] or simply age, their propulsion is affected. Traditional powered wheelchairs are not always desirable solutions: their size, weight, maintenance requirements and price, as well as the psychological considerations associated with them often make them less attractive to users. Several alternative solutions have been suggested, such as arm cranks[2,3], or power assistance of manual chairs[4].

Researchers have widely used physiological variables to evaluate the efficiency of wheelchair propulsion[2,3,5,6]. The lower the physiologic demand the later the user will experience fatigue, thus facilitating longer distance and higher speed travel on more varied terrain.

Power assistance provided by Yamaha JWII hubs is added proportionally to the user's input and seeks to significantly ease manual wheelchair propulsion.

RESEARCH QUESTION

This study sought to quantify the effect of the JWII on physiological efficiency by measuring and analyzing the difference in metabolic energy consumption during manual wheelchair propulsion with and without the JWII power assist hub.

METHOD

Four female and six male full-time manual wheelchair users were recruited from the laboratory's database. Subjects were age 33.7+/-9.7 years (mean+/-SD), height 174+/-3.3 cm and weight 68+/-3.2 kg. Nine individuals with T2-T9 level Spinal Cord Injury and one with Multiplex Sclerosis participated. All subjects gave their written consent.

Subjects were asked to propel both their own chair and a Quickie GPV equipped with a JWII in a controlled environment. The chairs were mounted on a computer controlled wheelchair dynamometer[7], which was set on normal, slight and moderate resistances. During each trial motor speed and motor torque values were recorded from the sensors attached to the dynamometer. Mean user power output applied to the rollers for each condition was calculated based on these recordings. Propulsion speed of the trials was 1.8 m/s for the normal and slight resistances and 0.9 m/s for the normal, slight and moderate resistances. The order of the trials was randomized.

	Power (Watts)	
	Without Yamaha	*With Yamaha*
2m/h, normal resistance	9	10
2m/h, slight resistance	11	14
2m/h, moderate resistance	11	15
4m/h, normal resistance	20	23
4m/h, slight resistance	25	29

Table1. Average power applied to the dynamometer rollers (Watts).

Oxygen consumption (VO_2) was measured with a Sensormedics® Metabolic Measurement Cart and heart rate (HR) was measured with a Polar heart rate monitor. Three minutes of physiologic data were collected during each of the ten trials.

Since the data was not normally distributed, Wilcoxon signed ranks test was used for statistical analysis. In addition, both chairs were compared across the five conditions using a mixed model analysis. SPSS and SAS software were used for statistical data analysis.

RESULTS

The JWII had significantly lower ($p<0.05$*) mean and peak VO_2 values in all 5 conditions, while mean and peak HR was significantly lower in 3 of 5 trials with the JWII than the traditional chair. (Table 2). When using the mixed model, both HR and VO2 mean and peak values were significantly lower for the JWII at faster speeds regardless of the resistance level.

MEAN VALUES	VO_2			HR		
	Mean ± SD with JWII	*Mean ± SD without JWII*	*P*	*Mean ± SD with JWII*	*Mean ± SD without JWII*	*P*
1.8 m/s, normal resistance	7.8 ± 1.6	10.8 ± 2.8	0.022	113 ± 23	129 ± 27	0.059
1.8 m/s, slight resistance	8.0 ± 1.4	13.0 ± 2.8	0.005	111 ± 20	134 ± 24	0.005
0.9 m/s, normal resistance	5.5 ± 0.8	6.9 ± 1.2	0.005	95 ± 16	105 ± 20	0.022
0.9 m/s, slight resistance	5.9 ± 1.0	7.3 ± 1.5	0.005	98 ± 21	106 ± 19	0.066
0.9 m/s, moderate resistance	5.9 ± 1.3	7.5 ± 1.8	0.005	100 ± 19	106 ± 24	0.037

Table 2. Oxygen ventilation (VO2) and heart rate (HR) results.

DISCUSSION

The results of this study indicate that significantly lower physiologic demand of wheelchair propulsion can be achieved by power assistance. As shown in Table 1, power measured by the dynamometer is higher when using JWII. This is due to the fact that it is easier to achieve and maintain the same speed with the power assisted device than without. Since physiologic results are lower with power assistance, the effect size is essentially larger.

There is little or no difference found in VO_2, HR and power at 0.9 m/s (2 m/h) between slight and moderate resistances. (Table 1 and 2.) This might be due to the insufficient difference between the levels of resistances.

Both examined variables showed that the higher the speed the greater the difference in metabolic demand with the JWII. Since JWII adds power proportionally to the user's input, this logically means that more additional power benefit the user at higher speed. However, another reason of this can be that the subjects propelled an unfamiliar chair, consequently, at normal pace they felt more comfortable propelling their own chair. During the testing subjects implied that it was hard having to propel slowly with the JWII; the majority stated that it was demanding to keep the pace down at 0.9m/s (2m/h). Metabolic data proves the advantage of power assistance at lower as well as higher speeds. However, these results also suggest that power assistance is potentially most advantageous outdoors, when propelling long distances.

Reduced physiological demand of wheelchair propulsion can be beneficial for many wheelchair users. The major benefit, however, will probably be when aging, or those in transitional status between manual and powered chairs. In addition, some individuals who currently use powered chairs might find it possible to propel a power assisted chair. Further analysis is needed to distinguish between the different types of power assisted wheelchairs currently being developed, as well as to analyze them in a "real life" setting.

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EFFECT OF PUSHRIM COMPLIANCE ON PROPULSION EFFICIENCY

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ABSTRACT

Wheelchair propulsion is a repetitive activity and as a result, users are prone to injury. Use of a compliant pushrim is one proposed solution to reduce the likelihood of developing upper extremity pain and injury. Compliant pushrims incorporate flexibility between the wheel and the pushrim, which absorb impact forces during propulsion. This study investigated the effects of three compliant pushrim designs on propulsion efficiency. Results of this study indicate a trend toward a reduction in metabolic demand during wheelchair propulsion using the compliant pushrim concepts. It was concluded that the losses in relative mechanical efficiency are less significant than the gains provided by the increased degrees of freedom of the pushrim, which allow users to better optimize their propulsion technique.

BACKGROUND

Use of a compliant pushrim is one proposed solution to reduce the likelihood of developing upper extremity pain and injury in manual wheelchair users. Compliant pushrims incorporate flexibility between the wheel and the pushrim, which absorb impact forces during propulsion. Due to this flexibility, some of the energy transmitted to the pushrim is absorbed, and not transmitted into propulsion of the wheelchair, thereby resulting in a decrease in the relative mechanical efficiency (1). Relative mechanical efficiency is not a comprehensive indicator of efficiency since it does not address the non-tangential forces applied to the pushrim nor the metabolic demands on the user.

A better estimation of efficiency might be the percentage of the resultant force directed tangentially to the wheel during propulsion. The percentage of the resultant force directed tangentially to the wheel was shown to be an indicator of efficiency during wheelchair propulsion using a standard rigid pushrim (2). However, later studies suggest that it may be misleading to measure efficiency in terms of one particular force direction since it may be the most optimal direction, given the constraints of the musculoskeletal system within the wheelchair system (3). Since compliant pushrims reduce constraints placed on the upper extremity during propulsion by increasing the degrees of freedom of the pushrim, using force direction as a predictor of efficiency may be inappropriate. A comprehensive understanding of the effects of pushrim compliance on propulsion efficiency will therefore require measurement of metabolic response during propulsion.

RESEARCH QUESTION

Compliant pushrims absorb some of the energy applied to the pushrim during wheelchair propulsion but also reduce the physical constraints placed on the upper extremity during propulsion, thereby allowing the user to better optimize propulsion technique. What are the net effects of pushrim compliance on the metabolic demands of the wheelchair user during propulsion?

METHOD

Subjects were asked to propel at a self-selected speed for three minutes using each of three compliant pushrim prototypes and a rigid pushrim on a stationary dynamometer, set to simulate propelling across a 2% (1:50) grade. The same procedure was then followed with the dynamometer set to simulate propelling across a 3.3% (1:30) grade. During propulsion, the metabolic response of the subjects and propulsion velocity of the wheelchair were measured.

Five non-disabled subjects (1 female; 4 males) with an average age of 21.6 years (range 19-27 years) and an average weight of 77.8 kg (range 64-91 kg) participated in the study. A rehab lightweight wheelchair (Quickie Carbon, Quickie Designs) with 24 inch pneumatic rear tires was used as the test wheelchair. Subjects rated themselves as above average in fitness level and were moderately experienced wheelchair riders but not full-time wheelchair users.

The compliant pushrims, Shock Mount, Extension Spring, and Bungee Cord were named after their interface mechanisms. The force-displacement characteristics of the compliant pushrims were determined by measuring pushrim translation and rotation after hanging a series of weights, tangentially from the pushrim (Figure 1). The dynamometer consisted of two independent rollers connected to DC motors via belts. The resistance of the motors was altered using an electronic load (Hewlett Packard model 6060B). A tachometer mounted to the roller shaft was used to measure the angular velocity of the roller, which was then used to determine the propulsion velocity. Subjects monitored their propulsion velocity through a display mounted in front of them.

Physiological measurements of ventilation and oxygen consumption were made using a metabolic data collection cart (Sensormedics 2900) through a one-way non-rebreathing valve (Hans-Rudolph) and using a nose clip. Heart rate was measured using a chest-mounted monitor (Polar). A 30-minute rest period was given between propulsion tests.

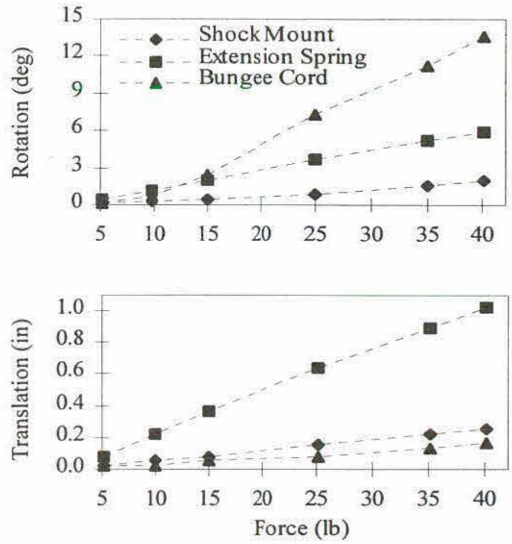

Figure 1. Pushrim rotation and translation force-displacement characteristics. Translation is the vector sum of the horizontal and vertical translations.

Metabolic response during the final minute of propulsion was used for comparison. The results obtained with the rigid pushrim and each of the compliant pushrim concepts were compared for each for the dynamometer resistance conditions. A ratio of the average propulsion velocity to oxygen consumption was used as an indicator of propulsion efficiency. Results were compared using a 2-tail paired sample t-test and determined to be statistically significant if $p<0.05$.

RESULTS

The average propulsion velocities using the rigid pushrim and each of the compliant pushrims were not significantly different. For propulsion on a simulated 2% grade, use of the Extension Spring concept resulted in a 30.1% reduction in ventilation, 23% reduction in oxygen consumption, and a 7.9% reduction in heart rate (Tables 1, 2). For propulsion on a simulated 3.3% grade, the Bungee Cord concept resulted in a 10.1% reduction in oxygen consumption and a 10.9% improvement in the efficiency indicator. The Shock Mount concept appeared to reduce metabolic demand, although the results were not statistically significant. Using a less rigorous statistical significance level of $p<0.08$, the Shock Mount concept resulted in a 4.1% reduction in heart rate and a 6.6% improvement in the efficiency indicator.

Table 1. Metabolic and propulsion measures for the 2% grade resistance condition (n=5) (*=p<0.05).

Pushrim	Propulsion Velocity (m/s)	Ventilation (L/min)	Oxygen Consumption (L/min)	Heart Rate (b/min)	Efficiency Indicator (m/s)/(L/min)
Rigid	1.36	33.62	0.99	101.23	1.39
Shock Mount	1.41	30.09	0.97	97.07	1.48
Extension Spring	1.20	**23.51***	**0.76***	**93.18***	1.63
Bungee Cord	1.40	29.43	0.98	93.78	1.46

Table 2. Metabolic and propulsion measures for the 3.3% grade resistance condition (n=5) (*=p<0.05).

Pushrim	Propulsion Velocity (m/s)	Ventilation (L/min)	Oxygen Consumption (L/min)	Heart Rate (b/min)	Efficiency Indicator (m/s)/(L/min)
Rigid	0.71	32.33	1.11	94.97	0.66
Shock Mount	0.72	32.52	1.09	94.10	0.70
Extension Spring	0.76	31.14	1.16	97.07	0.68
Bungee Cord	0.70	30.78	**1.00***	94.31	**0.73***

DISCUSSION

Results of this study indicate a trend toward a reduction, rather than an increase in metabolic demand during propulsion using the compliant pushrim concepts. It was concluded that the losses in relative mechanical efficiency are less significant than the gains provided by the increased degrees of freedom of the pushrim, which allow users to better optimize their propulsion technique. The Shock Mount concept was found to reduce metabolic demand only after applying a less statistically rigorous test. Other pushrim performance requirements including appropriate impact absorption and maintenance of maneuverability will need to be considered in order to optimize compliance characteristics.

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CLASSIFICATION OF STROKE PATTERNS IN MANUAL WHEELCHAIR USERS

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ABSTRACT

An abundance of biomechanical research has been published on manual wheelchair users (MWU), however small subject groups investigating propulsion patterns created generalizations and inadequate statistical power (1,4,5,6). The aim of the study was to categorize MWU according to the propulsion stroke pattern and to establish if variances between speeds and sides exist. A sample of 43 experienced MWU volunteered for the study. Kinematic data were collected at 60 Hz by a six-camera (OPTOTRAK) system and analyzed. Four different propulsion stroke patterns (semi-circular (SC), single looping-over-propulsion (SLOP), and double looping-over-propulsion (DLOP), and arcing (ARC)) were ascertained by tracing the position of a marker at the 3rd MP joint (4). The propulsion strokes of the subjects varied between speeds of 0.9 and 1.8 m/s (N=19) and between sides (N=8, N=8). Future investigations should focus on the significance of the different propulsion stroke patterns in MWU.

INTRODUCTION

The propulsion patterns of manual wheelchair users (MWU) have been studied in the past (1,4,5,6). However none of the previous studies have used a large number of MWU propulsion strokes or users. Identifying the types of propulsion patterns in MWU using a kinematic analysis may help to determine who is at risk for developing upper extremity injury. Sanderson and Sommer investigated propulsion patterns in three male MWU that were world-class athletes. They recognized two distinct stroke patterns (circular and pumping) of MWU and found no changes in the style of the stroke pattern over the 80-minute testing period. Veeger et al. studied the stroke patterns of five male MWU athletes. The stroke patterns were assessed at four speed trials of 0.56, 0.83, 1.11 and 1.39 m/s and no stroke pattern changes were reported between speed trials. Plots of the 3rd metacarpophalangeal (MP) marker revealed two dissimilar stroking patterns (circular and pumping) as also reported by Sanderson et al. and Chou et al. Shimada et al. examined seven-experienced MWU in a standard wheelchair and found three distinct stroke patterns (semi-circular (SC), single looping-over-propulsion (SLOP), and double looping-over-propulsion (DLOP)). The (SC) pattern was recognized by the hands falling below the propulsion pattern during the recovery phase (5). The (SLOP) pattern was identified by the hands rising above the hand rim during the recovery phase (5). The (DLOP) pattern begins with the hands rising above the propulsion pattern then crossing over and dropping under the propulsion pattern during the recovery phase (5). Only one of the subjects changed his /her stroke pattern over two different speeds (1.3 and 2.2 m/s). Earlier studies have only collected data on one side of the subjects based on the assumption that the MWU propulsion strokes were symmetrical. The purpose of the study was to classify MWU stroke patterns and to determine if there are differences between speeds and sides.

METHODS

Subjects. Forty-three experienced (11.53 years post operation, SD = 6.09) manual wheelchair users (30 male and 13 female) with spinal cord injuries of T4 level or below volunteered for the study. The mean age of the subjects was 36.2 (SD = 10.44) years (range = 20.7 to 68.8). Informed consent was obtained from each participant prior to the start of the study.

Kinematic measurement system. A six-camera 3D-motion analysis system (OPTOTRAK, Northern Digital Inc.) was used to collect the kinematic data. The kinematic data were collected at 60 Hz.

Experimental protocol. Each subject's individual manual wheelchair was secured onto a dynamometer (3). All of the subjects performed five propulsion trials at two steady state speeds of 0.9 m/s and 1.8 m/s. During the propulsion trial, kinematic data were collected for 20 seconds. The x and y coordinate positions of the 3rd MP joint were plotted to identify the propulsion stroke patterns of each subject.

RESULTS

From the plots of the 3rd MP positions three distinct stroke patterns (SC, SLOP, DLOP) as stated by Shimada et al. were identified. In addition, MWU were identified as having an arcing (ARC) motion. This (ARC) pattern occurs when the 3rd MP follows an arc along the path of the push rim during the recovery phase of the stroke. The four types strokes patterns (ARC, SC, SLOP, DLOP) are illustrated on figure 1. Table 1 reveals the four types of stroke patterns the subjects performed. Table 2 lists the number of subjects that demonstrated differences in stroke patterns between sides and speeds.

Figure 1. Stroke patterns (semi-circular (SC), single looping-over-propulsion (SLOP), double looping-over-propulsion (DLOP), and arcing (ARC)) for both speeds of 0.9 and 1.8 m/s.

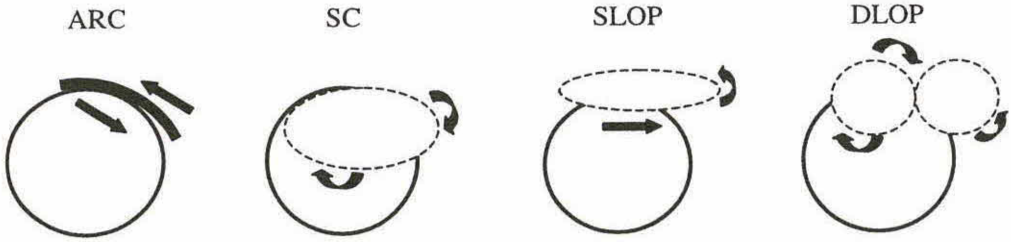

Table 1. The number of manual wheelchair users that displayed the four types of stroke patterns: Arcing (ARC), Semi-circular (SC), Single looping-over-propulsion (SLOP), and Double looping-over-propulsion (DLOP).

Classifications	0.9 m/s right side	0.9 m/s left side	1.8 m/s right side	1.8 m/s left side
ARC	6	2	9	10
SC	10	11	6	5
SLOP	16	16	18	16
DLOP	11	14	10	12

Table 2. The number and percentage differences in stroke patterns between right and left side at both 0.9 and 1.8 m/s and the differences in the stroke patterns between speeds only.

Different stroke patterns between right and left side for 0.9 m/s	Different stroke patterns between right and left side for 1.8 m/s	Different stroke patterns between 0.9 and 1.8 m/s
8	8	20
18.60%	18.60%	46.51%

DISCUSSION

Kinematic analysis of propulsion stroke patterns may be an important element needed to assess the possible causes of common repetitive strain injuries related to manual wheelchair use. Previous studies have examined the stroke patterns of MWU with small subject groups, which can lead to oversimplifications and limit the statistical strength (1, 4, 5, 6). Shimada et al. found that one out of seven (14.28%) subjects displayed stroke pattern differences between two different speeds. This study found that 20 out of 43 (46.51%) subjects displayed different stroke patterns between 0.9 and 1.8 m/s. The plotting of the 3rd MP joint in this study revealed four distinct stroke patterns of MWU. An additional stroke pattern (ARC) was identified that was similar to the pumping stroke pattern reported by Sanderson et al. and Veeger et al. Fourteen subjects (32.6%) displayed a difference in stroke patterns between sides and two subjects exhibited variations between sides and speeds. This asymmetry was not found in any previous studies and may be due to the small subject groups and unilateral analyses (1,2,4,5,6). These side to side differences may be a result of many factors including pain/injury, muscle imbalance, fatigue, seating positioning, weight distribution, balancing of the trunk, level of spinal cord injury, and the training attained at post injury.

CONCLUSION

The difference found among and within subjects provides valuable information pertaining to the assumption that MWU have synchronized rhythmic movements. These differences in stroke patterns in MWU require more attention and further investigation. Applied forces, stroke efficiency and frequency of strokes with the relationship to stroke patterns are areas of interest that should be considered in future studies.

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MEASUREMENT OF TRAJECTORY AND PUSH/PULL FORCE FOR MANEUVERING A WHEELED LIFTING DEVICE

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ABSTRACT

This paper describes maneuvering forces of a wheeled lift. A measurement system for trajectories of the wheeled lift was constructed. It included a dot scale, which was put on a ceiling, and a video camera, which was attached to the lift. Each dot on the matrix was digitized using a Peak Performance System. The trajectory was calculated from these data. A reverse dynamic analysis method was developed for calculating the maneuvering forces and moments. A result of an experiment using this system showed that a nurse added less wasteful forces and received smaller low back loads than an amateur when they moved a patient between a bed and a wheelchair using the wheeled lift.

BACKGROUND

Wheeled lifting devices are useful for reducing care giver's load when transferring a dependent patient between bed, wheelchair and other places. One of their good features is that they can be used more flexibly than overhead lifts. However, Santaguida et al. reported that wheeled lifts were rated as being more stressful than overhead lifts on the Borg scale[1)]. Measurement of low back loads during use of a wheeled lift showed that high loads were applied to the user's low back when moving the lift[2)].

RESEARCH QUESTION

The objective of this study was to develop a method of measuring the applied forces and moments when using a wheeled lift in real situations

METHOD

Trajectories of movement of a wheeled lift when transferring a person, who weighed 61kg, between a bed and a wheelchair in a hospital room of Sunnybrook Health Science Centre were measured using a video camera that was attached to the lift pointing upward toward the ceiling. An array of dots, spaced at 10cm, was attached to the ceiling. The dot scale was recorded by the video camera. Then, the video data were digitized using a Peak Performance system. Three coordinate systems were defined to calculate trajectories of the lift; camera coordinate system, lift coordinate system and dot scale coordinate system. A transformation matrix from the lift coordinate system to the camera coordinate system (Ml-c) was made from calibration data. A transformation matrix from the camera coordinate system to the dot scale coordinate system (Mc-d) was calculated from digitized data. So, a transformation matrix from the lift coordinate system to the dot scale coordinate system (Ml-d) was calculated from Equation (1).

$$Ml\text{-}d = Mc\text{-}d \times Ml\text{-}c \qquad (1)$$

Since any points on the lift could be expressed in the dot scale coordinate system by using Ml-d, the trajectories of the lift could be measured.

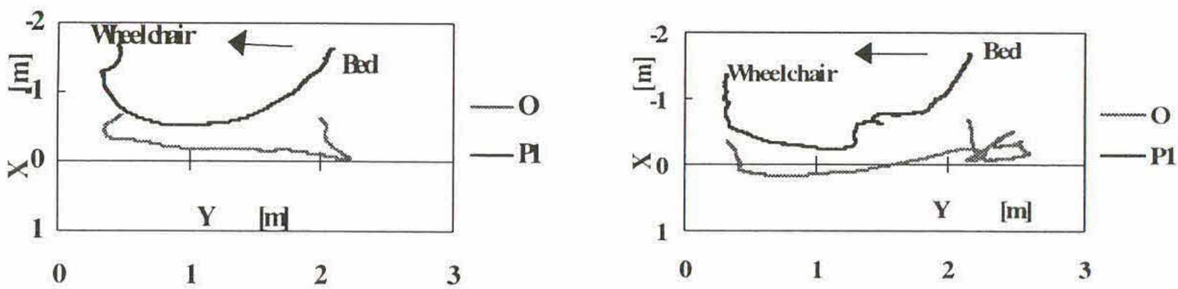
To estimate maneuvering forces, a mathematical lift model was constructed, which included a castor model and a whole lift model. Forces generated by castors during movement were divided into two types. One is the frictional force of the rotating wheel. The second is the friction moment of swiveling a castor. Castors move in three ways; 1) pure rotation, 2) pure swiveling and 3)combining rotation and swiveling. For pure rotation the coefficient of friction was estimated as 0.045 based on measurement data. For pure swiveling the coefficient of friction was estimated as 0.00375m based on measurement data. In the mixed case the rotational friction coefficient was assumed to be the same as for pure rotation. The swivel friction coefficient was related to a parameter, alpha, which was defined as the change of swivel angle divided by the change of rotation angle[3]. The swivel frictior coefficient was set to 0.00375m for values of alpha greater than 1, an interpolated value between 0.00375m and -0.00375m for values of alpha between –1 and +1, and to -0.00375m for alpha less than -1. The rotation angle and the swivel angle of the four castors were estimated from the trajectory data of the lift.

The lift model was also constructed. Weight, center of mass and inertia were measured from the real lift. Acceleration and angular acceleration were calculated from the trajectory data. In addition, an estimation of vertical force on each castor was needed for calculation of the friction force and moment on each castor. An assumption was necessary. The ratio of the sum of the vertical forces on the two front castors to the sum of the vertical forces on the two rear castors was assumed to be constant. And, the ratio of the sum of the vertical forces on the two right castors to the sum of the vertical forces on the two left castors was also assumed to be constant. Forces and moments on the handle of the lift were calculated through an equation of motion with parallel transformation and rotation.

RESULTS

Two subjects were recruited for the measurement. One was a nurse, who had 6 years of experience using lifts, and the other had never used a lift. Fig. 1 shows the trajectory of the lift when moving the patient from the bed to the wheelchair. Point O is the lowest point of a mast of the lift and point P1 is 1m forward of the point O. The subjects pulled the lift out from the bed, then turned it toward the left. Next, they pushed the lift beside the bed and turned it toward the right then pushed it to the wheelchair. The trajectory created by the nurse was smoother than that of the amateur. In particular, the amateur seemed to have difficulty when turning the lift toward the left after pulling it out from the bed.

Fig.2 shows forces and twisting moments applied to the handle of the lift. The force data reveals that the nurse applied steadier forces than the amateur. In particular, the forces exerted toward the left/right by the amateur varied considerably. The nurse applied a larger peak pull force (98N) and the amateur exerted a larger peak left/right force (47N). The amateur applied more variable and larger peak twisting moments than the nurse. The largest peak moment applied by the amateur was



(a) Nurse (b)Amateur

Fig. 1 Trajectory of the wheeled lift

estimated to be 69Nm, as compared to 42Nm for the nurse.

DISCUSSION

This method enabled easy measurement of the trajectory, and estimation of the forces and the moments applied when maneuvering a wheeled lift. It facilitated measurement in a real hospital room because no instrumentation was required other than a video camera and a printed dot scale on the ceiling. The lifting equipment required no modification or special instrumentation. Measurement in the field is important when evaluating these assistive devices and this technique may be convenient.

Obviously this single test serves only as an illustration of the potential application of this method and the specific results can not be generalized. In this case, the amateur applied larger forces toward the left and the right and larger twisting moments than the nurse. These forces and moments are assumed to generate twisting moments on a caregiver's low back[4]. Perhaps the nurse had developed a technique of moving the lift through experience that minimized peak moments and forces.

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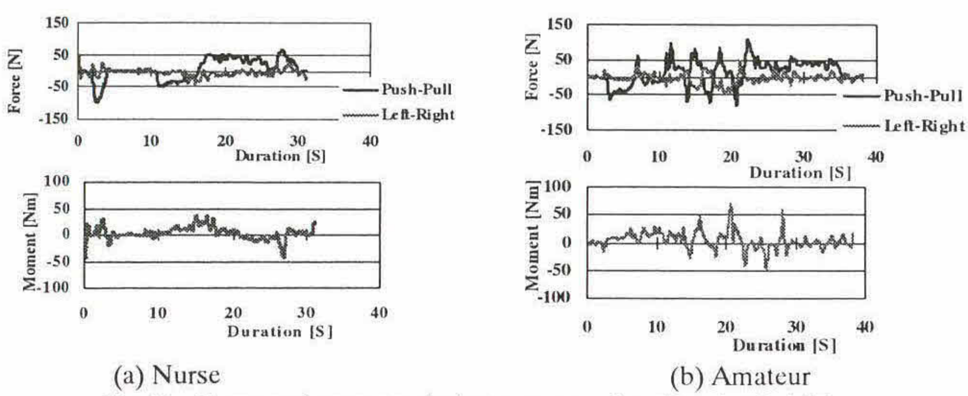

Fig. 2 Force and moment during maneuvering the wheeled lift.

COMPARISON OF WHEELCHAIR EXERCISE WITH AND WITHOUT GAMEWHEELS SYSTEM USING PHYSIOLOGICAL DATA

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ABSTRACT

The sedentary lifestyle of manual wheelchair users (MWU) could be a contributing factor in cardiovascular diseases becoming a major health concern for the wheelchair population. The GAME^{Wheels} system (GW) is an interface between a portable roller set-up and computer. It allows a MWU to control a computer video game with the forward and rearward propulsion of their wheelchair. Playing video games might motivate these individuals to exercise on a regular basis. Nine MWU exercised with and without the GW. Physiological data were collected during each trial. Each trial was 20 minutes long, with at least 2 hours of rest between trials. Paired t-test were used to analyze the physiological data between with and without GW. There was a significant difference for the transition period (last minute of warm-up & first minute of exercise) for group's: average ventilation ($p = .020$), average VO_2 ($p = .060$), peak ventilation ($p = .039$), & peak VO_2 ($p = .017$).

BACKGROUND

Jones and Sanford reported that there about 1.4 million MWU in the U.S. (1). Research has shown that individuals who use wheelchairs for their mobility have a decreased activity level as compared to before their use of the wheelchair (2-4). The propulsion needed to accomplish daily living activities does not help to improve or maintain their cardiovascular fitness level (2).There may be additional functional limitations to the cardiovascular system, due to the spinal cord injury (SCI), along with fatigue and discomfort that might hinder or decrease their desire to exercise (5).

The variety of equipment and/or a regular exercise program may not be available for the MWU. Individuals with a SCI have reported that exercise programs using arm cranks or roller systems can be boring and supply little or no motivation to maintain the exercise program (3 & 4). Research has shown that a sedentary lifestyle coupled with MWU's lower rate of oxygen consumption has made cardiovascular diseases a major health concern for MWU (2). Exercise training programs for MWU has shown an improved cardiovascular and metabolic function during maximal and sub-maximal testing. Exercise has been shown beneficial to the cardiovascular system and if exercise can be made fun then there might be motivation to maintain an exercise program.

This study investigated the motivational factor of the GW and the physiological response of the MWU during exercise with and without playing the computer video game.

METHODS

Nine MWU were asked to come to the VA Rehabilitation R & D Center of Excellence/Human Engineering Research Laboratories to use the GW and collect physiological data. There was a wide range of age (34 ± 10.43), years post injury (14 ± 10.74) years, and level or type of injury (T2-12, MS & CP). The individuals were assisted on and secured to the portable roller system equipped with the GW and the computer video game. There were Nashbar magnetic brakes on each roller which has seven discrete steps for adjustment. The subject got acquainted with the system, and the magnetic brakes were adjusted in order to find the resistance level, for each individual, at which they thought it simulated propelling over a flat surface.

A standard submaximal oxygen consumption test was completed on each subject. The VO_2/kg (oxygen consumption per body weight) and heart rate (HR) prediction graph in Montoye et al. (6) was used as a guide line in order to avoid a maximum test. A SensorMedic metabolic cart was used to collect ventilation and oxygen consumption (VO_2). A pretrial calibration was done with the metabolic cart prior to each testing session. HR was monitored using a Polar HR monitor during the submax and exercise testing. The max HR for arm work was calculated with the following equation (7):

220 - age * .80 (arm work)

VO_2 max from the submax test and HR max were used as safety guidelines for the exercise trials. The exercise trials consisted of 20 minutes (2 minutes of warm-up, 16 minutes of exercise, 2 minutes of cool-down). The 16 minutes of arm exercise was determined from 80% of the accepted norm time of 20 minutes for leg exercise. The upper extremities have a smaller muscle mass therefore the exercise time is decreased. The exercise trials with and without GW were randomized.

After the submax test was completed, subjects were allowed sufficient time to rest. The subjects were allowed to get re-acquainted with the GW and the video game. Need for Speed II (an oval race car track) game was selected based on the results of prior testing. The software of the video game was set-up to the individuals' comfort level, thus trying to maximize the individual's game play time. The subjects were instructed to play the video game (propelling their wheelchair). The only verbal cues given were to notify them of the end of warm-up and the end of exercise. The video game display provided race car speed, lap elapsed time, number of laps completed and position within the eight cars (computer controlled other cars proportional to the wheelchair user's speed). The individual could also monitor their HR and their own wheelchair speed. HR, ventilation, and VO_2 were collected during the exercise trials.

The exercise trial without the GW used the same protocol except there was no video game play. The individual had their wheelchair speed and HR only. Physiological data was collected. A short open-ended questionnaire was completed as well.

Paired t-tests ($\alpha = .05$) were used for statistical analysis of the physiological data (group average and group peak of HR, ventilation, and VO_2). The exercise period was divided into a transitional period (last minute of warm-up & first minute of exercise), middle 2 minutes and last 2 minutes of exercise.

RESULTS

The average and peak HR showed no significant difference for the group during the three periods analyzed for comparison between exercise with and without the GW. The average and peak ventilation showed a significant difference ($p = .020$ & $p = .039$, respectively) during the transitional period for exercise with and without the video game play. The peak VO_2 (oxygen consumption) showed a significant difference ($p = .017$) during the transitional period for exercise with and without the video game play. The average VO_2 during the transitional period trended towards significance ($p = .060$). Although the average and peak values for the ventilation and VO_2 were higher for GW than no GW, the difference was not significant for both middle and last periods. The questionnaire showed the subjects all responded positively about the GW helping them to exercise. They stated that the idea of being able to play their favorite game would help them to exercise regularly.

DISCUSSION

The GAME[Wheels] system allows wheelchair users to play any commercially available computer video game to help motivate them to exercise. The system might help take away the boredom factor during exercise with a roller system, that was reported by previous research. The subjects tested reported that they felt the GW would help them workout on a regular basis. The subjects tested represented a wide range of age, years post injury and level or type of injury. The HR was not significantly different throughout the trials. Ventilation and VO_2 were significantly different in the transition period. This suggests that the MWU were able to elevate their ventilation and VO_2 faster when playing the video. Analysis of the group's average physiological data over the 16 minutes of exercise showed that the exercise without the video game did not reach the level of the video trial until more than half the exercise period was over. This suggests that the video exercise trial MWU were working harder or as hard throughout the entire exercise period. The higher and longer work rate for the video exercise trial might show more improvement in the cardiovascular fitness levels.
Future testing will involve more subjects. Also, the use of the SMART[Wheel] on the MWU's wheelchair to investigate a possible change in the propulsion forces that are applied to the pushrim that might lead the MWU susceptible to a secondary injury.

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SHOULDER JOINT FORCES AND MOMENTS DURING TWO SPEEDS OF WHEELCHAIR PROPULSION

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ABSTRACT

Manual wheelchair users (MWUs) are at an increased risk for developing shoulder joint pain and injury. Understanding the role of the shoulder during wheelchair propulsion may provide insight to the mechanisms of injury. Three-dimensional shoulder joint forces and moments were calculated for twenty-six MWUs based on a biomechanical model with a local coordinate system representation. The participants propelled at two constant speeds (0.9 and 1.8 m/s) while kinetic and kinematic data were collected. All force components were higher during the higher speed condition. A similar trend was found with the moments. Using a local coordinate system approach enables us to investigate clinically important wheelchair propulsion factors in anatomical terms.

INTRODUCTION

Repetitive loading on the shoulder joint has been implicated as a causative factor of pain and injury among manual wheelchair users (MWUs). Nearly one half of MWUs have shoulder pain and/or injury even after short periods of time in a wheelchair (1). While the shoulder joint is the most freely moving joint in the body, it is also one of the most unstable. Individuals with lower extremity dysfunction must rely extensively on their shoulders while performing many daily activities like wheelchair propulsion, transfers, and overhead lifts. Overuse of the shoulders may lead to chronic pain, shoulder joint degeneration or injury. Understanding the functionality of the shoulder during such tasks can provide insight into pain and injury prevention and treatment.

In vivo studies of the shoulders of wheelchair users have been conducted to obtain estimates of the shoulder joint forces and moments present during wheelchair propulsion. A biomechanical model is required with input parameters including upper arm kinematics, anthropometry and externally applied forces. Several models have been developed for determining shoulder kinetics, but few contain what may be key features for accurately depicting the loads and moments at the shoulder joint. The purpose of this paper was to explore the feasibility of a shoulder model developed by Cooper *et al.* for describing differences in shoulder joint forces and moments during two speeds of wheelchair propulsion (2). This model is unique in that it uses a local coordinate system analysis to represent 3-D shoulder biomechanics in reference to a movable trunk.

METHODS

Subjects. Twenty-six experienced MWUs gave written informed consent to participate in this study. The sample consisted of 16 men and 10 women with a spinal cord injury at the T-4 level or below. The average age and years post injury was 34.0 ± 7.6 years and 11.6 ± 5.5 years, respectively.

Dynamic Propulsion Trials. Subjects' own personal wheelchairs were fitted with SMART^{Wheels}, force and torque sensing pushrims (3). Skin mounted LED markers of the OPTOTRAC motion analysis system (Northern Digital, Inc.) were attached to the following bony landmarks: acromion process, lateral epicondyle, olecranon, 3rd and 5th metacarpalphalangeal joints, radial and ulnar styloids. A rigid body made of carbon fiber composite was secured to the sternum to measure trunk movement. Wheelchairs were secured to a dynamometer with a resistance comparable to that of a tile floor. The subjects were instructed to push at two constant speeds: 0.9 m/s (2mph) and 1.8 m/s (4mph) for 20 seconds during which 3-D force (240 Hz) and motion data (60 Hz) were collected.

Application of the Glenohumeral Joint Model: The biomechanical model used in this study was based on an inverse dynamic approach with applied pushrim forces, anthropometric data, and kinematic parameters as the input variables and three-dimensional (3-D) shoulder joint forces and moments as the output variables (2). The segments of the upper arm were modeled as ball and socket joints. Equations derived from free-body diagrams of link segment models were used to construct a numerically stable algorithm for calculating the net muscle moments and joint forces for the wrist, elbow and the shoulder. Local coordinate systems at each joint and the trunk enabled for the net muscle forces and moments to be expressed in an anatomical reference system. The model algorithm was implemented in MATLAB (Mathworks, Inc.). A single matrix equation was used to calculate joint net forces and moments for each sample instant in time:

$$\vec{r}_p = \Phi\vec{r}_d + I\vec{a} + \Omega I\vec{\varpi} + \vec{M}g$$

where, $\vec{r}_p$ = force and moment reaction vector at the proximal end of a segment

Φ = matrix of lengths (for each segment) along the x, y, and z axes

$\vec{r}_d$ = force and moment reaction vector at the distal end of each segment

I = mass and inertia matrix

$\vec{a}$ = linear and angular acceleration vector

Ω = cross-product matrix containing components of the segment of angular velocity

$\vec{\varpi}$ = angular velocity vector for cross-product component of joint forces and moments

$\vec{M}g$ = mass * gravity and moment arm vector

Using the results of this equation and the coordinate transformation matrix for the trunk coordinate system, the shoulder joint reaction forces and moments could be expressed with reference to the moving sternum.

Each subject's first five right side strokes were used for analysis. Mean and peak magnitudes of the shoulder forces and moments were calculated over the push phase only. Shoulder variables were averaged across strokes to produce a single value. A paired t-test with $\alpha < 0.05$ was used to determine statistically significant differences in kinetic values between speeds.

RESULTS

All mean and peak 3-D force components were significant ($p < 0.001$) between speeds. The largest force component was that directed from the glenohumeral joint to the acromion. Of the moment components, only the peak horizontal flexion, peak horizontal extension, and peak sagittal extension were insignificant between speed conditions. The force and moment components demonstrating the largest magnitudes and differences between speed trials are shown in Table 1.

DISCUSSION

A biomechanical model has been developed to provide an approximation of the shoulder joint net muscle forces and moments experienced during wheelchair propulsion. In this application, the model was used to describe the forces and moments at the shoulder joint during propulsion at two constant speed conditions. All mean and peak shoulder force components were larger during the faster speed trial. The moment components followed a similar trend. The reaction force directed vertically up through the joint (glenohumeral to acromion) was higher than that of the other force components across speeds. This upward directed force likely causes the head of the humerus to

Table 1: Average and maximum shoulder forces in Newtons and moments in Newton • meter for propulsion speeds 0.8 and 1.9 m/s

	Average Values	Maximum Values	Average Values	Maximum Values
Force Components (N)	2 mph* (N=26)		4 mph* (N=26)	
Anterior to posterior	33.74 (11.04)	54.84 (16.91)	47.57 (15.28)	79.58 (29.42)
Glenhumeral to acromion	32.29 (11.11)	66.19 (23.05)	42.68 (15.34)	86.43 (33.53)
Compressive	17.92 (10.09)	34.46 (17.61)	29.31 (16.90)	54.96 (30.69)
Moment Components (N•m)				
Abduction	10.80 (6.79)	21.65 (12.76)	16.04 (8.20)	32.72 (17.03)
Sagittal Flexion	11.72 (7.93)	19.58 (12.57)	14.57 (10.30)	26.22 (17.77)
Internal Rotation	9.12 (5.49)	20.77 (14.73)	13.48 (5.97)	30.86 (15.28)

* All forces and moment values shown were significant between speeds ($p < 0.001$). Column data represent means and standard deviations are in parentheses.

superiorly displace against the corocoacromial arch compromising the space available for tendons, bursa, and other structures. Magnetic resonance images have shown that MWUs have in common abnormalities surrounding the corocoacromial arch (4). The largest moment found for the MWUs was for abduction. When the arm abducts, the head of the humerus rotates and slides within the glenoid cavity. Large abduction moments may cause the humerus to slide further outward requiring the excessive use of the stabilizer muscles to keep it from displacing from the joint.

CONCLUSIONS

Higher average and peak shoulder joint forces and moments were found with increasing speed. The results of this study help to identify the role of the shoulder muscles during wheelchair propulsion and provide insight into the mechanisms of shoulder pain and injury. Future studies will investigate the explicit relationship between shoulder joint kinetics and pain and injury in MWUs.

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EFFECT OF PUSHRIM COMPLIANCE ON PROPULSION KINETICS

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ABSTRACT

One proposed approach to reduce the likelihood of developing upper extremity pain and injury in manual wheelchair users is the use of a compliant pushrim. Compliant pushrims incorporate flexibility between the wheel and the pushrim, which absorbs impact forces during propulsion. This study investigated the effects of three compliant pushrim designs on propulsion kinetics. A 30% reduction in impact loading and a 6.6% reduction in peak forces were measured for the concept that allowed significant translational compliance. It has been concluded that pushrim translation relative the wheel is one method of reducing impact during propulsion. These results provide a more defined set of design specifications for future compliant pushrim designs.

BACKGROUND

Upper extremity pain and injury is common among manual wheelchair users. In a study of 239 manual wheelchair users, it was found that 64% of individuals with paraplegia and 55% of individuals with quadriplegia experienced upper extremity pain (1). Upper extremity pain limits manual wheelchair user strength and range of motion, decreasing mobility and function, thus resulting in a loss of independence.

A relationship has been established between the characteristics of the forces applied to the pushrim during propulsion and incidence of upper extremity injury. In a study of 31 manual wheelchair users, subjects with symptoms of injury propelled with greater peak forces than those without symptoms of injury (2). In a study of 34 manual wheelchair users, the rate of loading during impact was found to be an even stronger indicator of upper extremity injury (3). Both studies concluded that reducing these target propulsion kinetic characteristics should reduce the likelihood of developing upper extremity injuries. One proposed solution is the use of a compliant pushrim. Compliant pushrims incorporate flexibility between the wheel and the pushrim that absorb impact forces during propulsion.

RESEARCH QUESTION

The goal of a compliant pushrim is to reduce the peak and impact forces generated during propulsion. The amount and mechanical characteristic of the compliance required to accomplish such a reduction is unclear. How are propulsion kinetics affected by the use of three different compliant pushrim designs?

METHOD

Five male manual wheelchair users gave written consent and participated in the study. Subjects propelled their wheelchairs on a dynamometer at 1.4 m/s (3 mph) using a rigid pushrim and three compliant pushrim concepts. The compliant pushrims, Shock Mount, Extension Spring, and Bungee Cord were named after their interface mechanisms. The force-displacement characteristics of the compliant pushrims were determined by measuring pushrim translation and rotation after hanging a series of weights, tangentially from the pushrim (Figure 1). The dynamometer resistance was set to simulate propelling across a 2% (1:50) grade. Pushrim forces and moments were measured using two SMART[Wheels] (4) mounted on both sides of the subject's wheelchair. Force and moment data was collected for 20 seconds and then filtered. The SMART[Wheel] collects forces and moments in an absolute coordinate system, consisting of x (forward horizontal), y (upwards), and z (lateral outwards). A coordinate system transformation was conducted to convert the resulting forces from absolute to a local system about the pushrim. The resulting force components consisted of radial, tangential, and lateral with respect to the pushrim. The forces and moments were then normalized by subject weight, resulting in units of body weight (bw).

Ten consecutive pushes with an average velocity closest to that of the entire trial were used in the data analysis. Push frequency was calculated using the time to complete the ten pushes. The ten pushes were then averaged to form a single push, characteristic of the entire trial. The average rate of loading for the first 10% of the push was defined as the impact phase of the push. The peak force was determined across the entire push. The Contribution of the Tangential Force (CTF), often used as an indicator of mechanical efficiency was calculated as the vector contribution of the tangential component to the resultant force. The results obtained with the rigid pushrim and each of the compliant pushrim concepts were compared using a 2-tail paired sample t-test and determined to be statistically significant if $p<0.05$.

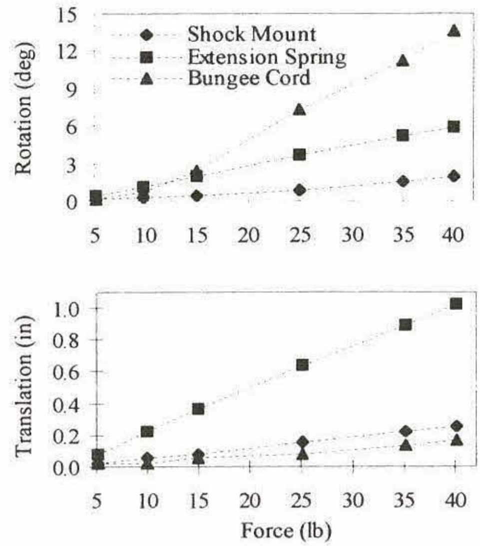

Figure 1. Pushrim rotation and translation force-displacement characteristics. Translation is the vector sum of the horizontal and vertical translations.

RESULTS

The average propulsion velocity and push frequency using the rigid pushrim and each of the compliant pushrim concepts were not significantly different. CTF values of the rigid pushrim (0.219) did not differ significantly from the Shock Mount (0.233), Extension Spring (0.226), or Bungee Cord (0.209) concepts.

The Extension Spring concept resulted in a 30% reduction in impact loading and a 6.6% reduction in peak forces (Figure 2) (Tables 1, 2). The Shock Mount concept appears to reduce peak forces, but not to a level of statistical significance. The Bungee Cord concept appears to increase both impact loading and peak forces, but not to a level of statistical significance.

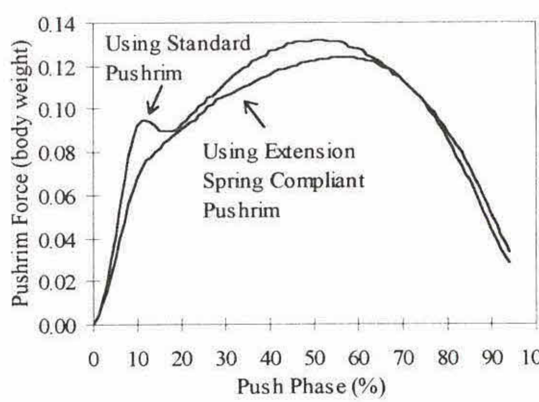

Figure 2. Impact force on the pushrim during constant speed propulsion using a standard pushrim and the Extension Spring concept. Average of 50 pushes (5 subjects, 10 pushes each).

Table 1. Average rate of loading over initial 10% of push (bw/s) (n=5) (*=p<0.05).

Pushrim	Resultant Force	Radial – Lateral Force	Tangential Force	Radial Force	Lateral Force
Rigid	2.599	2.315	0.434	2.070	1.012
Shock Mount	2.663	2.354	0.495	2.086	1.046
Extension Spring	**1.834***	**1.657***	0.222	**1.500***	0.675
Bungee Cord	3.549	3.275	0.489	3.043	1.115

Table 2. Peak propulsion forces (bw) (n=5) (*=p<0.05).

Pushrim	Resultant Force	Radial – Lateral Force	Tangential Force	Radial Force	Lateral Force
Rigid	0.140	0.121	0.072	0.112	0.047
Shock Mount	0.133	0.114	0.071	0.104	0.045
Extension Spring	0.128	**0.113***	0.069	0.106	0.040
Bungee Cord	0.144	0.133	0.073	0.127	0.040

DISCUSSION

The Extension Spring concept was specifically designed to allow both translational and rotational displacement relative to the wheel. The Bungee Cord Concept was designed specifically to restrict translational displacement while allowing rotational displacement relative to the wheel. The Extension Spring concept was shown to reduce impact loading, while the Bungee Cord concept appears to increase impact loading. It has been concluded that pushrim translation relative the wheel is one method of reducing impact during propulsion. The Shock Mount concept allowed some translation relative to the wheel, but not nearly that of the Extension Spring concept. With increased translational displacement characteristics, it is anticipated that the Shock Mount concept would also decrease impact loading and peak forces. These results provide a more defined set of design specifications for future compliant pushrim designs.

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USER POWER INPUT REDUCTION IN YAMAHA JWII PUSHRIM ACTIVATED POWER ASSISTED WHEELCHAIR

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ABSTRACT:

Yamaha JWII power assisted hubs have been developed to provide a transition between manual and powered chairs. Five manual wheelchair users propelled the JWII and their own chairs with selected speeds and resistances on a dynamometer. Torque data collected from both the dynamometer and the hubs, as well as the recorded metabolic data resulted in comparable power values. The JWII adds power proportionally to the user's input (providing 67% of the total power) and significantly ($p<0.05$) increases gross mechanical efficiency (17% with JWII vs. 8% with own chair). Significantly lower demand in physiologic and mechanical user power input is thus achieved, while still providing some exercise to the user.

INTRODUCTION

Scientists and industry have long been searching for alternate methods of mobility for people who currently use manual wheelchairs because of the high incidence of upper extremity injuries[1] and because of the transitional populations between manual and powered wheelchairs.

One method to evaluate wheelchair propulsion efficiency is the calculation of gross mechanical efficiency (GME). GME is calculated as the quotient of the total power generated by the system (user + wheelchair) and the physiological power. Previous studies have shown in traditional manual wheelchair propulsion, when the numerator of the GME consists of the user power only, it is usually 7-15%[2]. Increasing GME has been the goal of alternative designs, such arm cranks or hybrid-powered designs[3].

Yamaha Motor Corporation USA has designed power assisted hubs that are currently fitted on Quickie GPV frames. These hubs seek to multiply the user's power input by proportionally adding motor power. Consequently increase in the efficiency of wheelchair propulsion may be achieved.

RESEARCH QUESTION

This study was conducted in order to evaluate the level of GME increase with the Yamaha JWII hubs and to quantitatively describe power assistance.

METHODS

Two female and three male full-time manual wheelchair users were recruited from the laboratory's database. Subject's mean age (+/- SD) was 34.4+/-10.2, weight 65.6+/-11.13 kg and height 170.8+/-12.6 cm, all diagnosed with T3-9 level Spinal Cord Injury. Subjects were asked to propel a Quickie GP equipped with the JWII and their own chair on a computer controlled wheelchair dynamometer[4]. Propulsion speed was 0.9 and 1.8 m/s with the dynamometer set on normal, slight and medium resistances. The order of chairs, speeds and resistances was randomized.

Power (Watts)	*2 m/h normal resistance*	*2 m/h slight resistance*	*2 m/h medium resistance*	*4 m/h normal resistance*	*4 m/h slight resistance*
With Yamaha	10	16	16	25	32
With own chair	7	9	10	22	28

Table 1. Average power applied to dynamometer rollers (Watts)

Subjects propelled for 3 minutes for each trial: data were collected for the last 30 seconds. Motor speed and motor torque were sampled at 240 Hertz from torque sensors of the dynamometer. The power values calculated from these variables reflect the total work applied by the user and the chair (Table 1).

Creating a wired connection between the JWII hub's potentiometer and a laptop allowed us to also sample voltage signals at 240 Hertz that represent torque applied to the pushrims. Data was recorded by Labview software. Calibrating the hubs before the trials facilitated the translation of voltage to torque.

A Sensormedics® Metabolic Measurement cart was used to record metabolic variables. Oxygen consumption (VO2), Carbon Dioxide production (VCO2), and Respiratory Quotient (RQ) values were recorded by the cart. Translation to metabolic power followed the equations suggested by the manufacturers.

$$PhysPower[Watts] = \frac{1000}{0.239*24*3600} * \left\{\left(3.941 * VO_2\left[{ml}/{\min}\right]\right) + \left(1.1 * VCO_2\left[{ml}/{\min}\right]\right) * 1.44\right\}$$

Matlab, Excel and SPSS software were used to analyze the data. Paired t-tests were performed to calculate significance ($p<0.05$).

RESULTS

The speed achieved with power assistance is higher with Yamaha JWII than with subject's own chair, even though the same propulsion target speed was given. Consequently the total power (speed multiplied with the torque measured at the dynamometer) was found to be significantly higher with the JWII. The Yamaha hubs were found to triple the user's power input; 67% of the total power is produced by power assistance. Gross Mechanical Efficiency (GME) is thus significantly increased when compared to subject's own chair, while achieving higher speed. Average GME for the five trials was 8% with subjects' own chair and 17% with the JWII. Table 2 shows results averaged over all subjects and all trials.

	Speed (m/s)	*Total power (Watts)*	*User power (Watts)*	*Phys. Power (Watts)*	*GME (%)*
Own Chair	1.23	15	15	186	8
Yamaha JWII	0.99	21	7	126	17
Significance (p)	0.003	0.009	0.006	0.000	0.010

Table 2. Average results over five trials

DISCUSSION

Speed, power applied to the rollers, user power, physiological power and GME were calculated for both subjects' own chairs and the power assisted trials. For the regular manual wheelchair, user input accounts for all power dissipated by the dynamometer. However, when propelling the JWII this power is a result of two different sources: user (measured on pushrims) and power assistance. The amount of power added by the motors can thus be calculated. Accordingly, the GME with the different chairs is:

$$GME_{withOwnChair} = \frac{UserPower}{PhysPower}, \qquad GME_{withJWII} = \frac{UserPower + MotorPower}{PhysPower}$$

While subjects aimed to maintain the same propulsion speed with both chairs, they still achieved higher speed with JWII. This is a natural consequence of the ease of power assisted propulsion. This higher speed accounts for the higher total power calculated at the dynamometer rollers. The fact that GME is still significantly lower means that the difference is essentially even larger.

Power assistance of Yamaha JWII triples the user's power input. In other words, it adds double the amount of the power applied by the user. This proportion was found consequently in all trials whether 0.9 or 1.8 m/s speed was aimed: This suggests that the proportion of the power added by the motors is a consequent number, independent of user propulsion speed. In absolute values, however, this means that the higher the propulsion speed, the more additional power users gain from the Yamaha JWII.

The benefits of power assistance are important for many manual wheelchair users, particularly when aging. In addition, it eases the physical and psychological transition between manual and traditional powered wheelchairs. Through reducing gross mechanical efficiency it facilitates long distance propulsion by facilitating longer maintenance of higher speed on varied terrain. In the long term Yamaha JWII hubs might also contribute to the reduction of secondary injuries of MWUs, such as carpal tunnel syndrome and rotator cuff injuries.

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DEVELOPMENT OF MANUAL WHEELCHAIR FROM MOLDED ENGINEERING RESIN

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ABSTRACT

In response to consumer complaints about lack of durability, high cost, and excessive weight of most wheelchairs, a Phase I SBIR grant supported the development of a prototype low-cost, very lightweight wheelchair made from engineering resins. The chair uses a mirror image design to reduce the number of unique parts to 8, and has an interlocking design to allow complete assembly in 15 minutes. A FEA of the static loads on the chair was conducted, and a prototype full-scale model was machined from Nylon 6 with 30% glass-fiber. The assembled chair weighed 26.2 lbs. fully rigged. The prototype chair was submitted to U. of Pittsburgh for ANSI/RESNA fatigue tests. The design features and test results will be discussed as well as design and construction analysis.

BACKGROUND

Wheelchair users have complained for many years about the lack of durability, high maintenance, high cost of both the chair and repairs, and excessive weight of wheelchairs. More recently, the Stakeholders Forum on Wheeled Mobility at the RERC at Univ. of Pittsburgh, May 1999, (1) also reported consumer complaints about lack of durability and frequent repairs in manual wheelchairs. Cooper, et. al., (2,3) have documented the poor performance of "depot" and "lightweight" chairs. Cooper (2) reports none of the low-cost "depot" chairs and few of the "lightweight" chairs passed the ANSI/RESNA fatigue tests. Cooper (3) recommends third party payers buy the more expensive "ultralight rehab" chairs because these chairs have better durability and need fewer repairs. Cooper recommended rating chairs on an operating-cost per "cycle" basis, rather than purchase price alone.

The problem is not that third party payer limits funding; rather, it is a problem of poor performance in low cost wheelchairs. The number of states in the last eight years to add "wheelchair lemon laws" also is testament to the magnitude of the problem of poor performance. Quality design and performance standards are not improved by a law requiring one-year warranty on side frames and cross-braces. Manufacturers should improve the performance of their metal-frame chairs.

RESEARCH QUESTION

The research question is: can a modern engineering approach to wheelchair design produce, a low-cost (under $800), very lightweight (under 20 lbs. fully rigged) wheelchair with exceptional durability, as measured by exceeding the ANSI/RESNA manual wheelchair performance standard? The first step was to start with a clean slate, and no preconceived constraints. To keep costs low, part cost and assembly time should be minimized. Exotic materials that could easily lower weight also would raise the price. Injection molded components can be low cost, even when tooling costs are amortized into part cost. Common plastics such as PET, Nylon and Polypropylene have very good strength to weight characteristics when glass fiber is added. A mirror-image design would eliminate the need for right and left pieces, and simplify assembly. The use of "engineering resins" in the automotive and aircraft industry has advanced significantly the state-of-the-art in tooling and molding processes. Gas-assist injection molding can make molded components essentially hollow with uniform wall thickness, while eliminating "sink" lines or "dimples" in the finished surface. Automotive applications of engineering resins requires high strength over a wide temperature range, exposure to UV radiation (sunlight), and exposure to solvents and hydrocarbons, while maintaining good surface appearance. A design concept was proposed that would include these positive aspects.

METHODS

An interlocking, mirror-image design that required only 8 unique molded components was selected. The chair was designed in 3-D CAD software; part fit and dimensional details were developed. Non-linear Finite-Element-Analysis (FEA) modeling was conducted on the proposed model under different static loads. Glass filled plastics require a non-linear model. Static loads were modeled because dynamic load parameters are not well established and complicated the modeling. The FEA modeling was conducted by Allied Signal on a Cray supercomputer with 50,000 nodes in the model. The FEA model indicated none of the static load conditions created stresses in excess of 10,000 psi at any point in the model. Where high stress concentrations existed, design iterations were conducted to distribute the loads in that area. Unfortunately, there were not sufficient funds to conduct further FEA of design iterations to optimize weight to strength. The FEA model indicated the basic design was feasible, in that the stresses caused by the static loads were well within usable ranges for most common plastic reinforced with glass fibers.

A SBIR Phase I application was submitted to build a working prototype of the chair based on the results of the FEA model. The SBIR Grant was awarded in June 1999. The grant was to test the "proof of concept" by creating a prototype that could be submitted to fatigue testing to the ANSI/ RESNA wheelchair performance standard. This test was chosen as few low-cost manual wheelchairs can pass the standard. The Phase I prototype model was made by using the 3-D software to create a CNC tool path to machine identical parts to close tolerances. The components were made from Nylon 6 with 30% glass fibers. One concern with machining the prototype from glass filled resin is that there is no specific fiber orientation, and that cutting the fibers weakens the material. Allied Signal predicts a 20 to 30 % degradation of its strength characteristics. The design safety factor allows for this degradation. The mirror image design reduced the number of unique pieces to 8, although it requires 32 pieces for a fully assembled chair. The interlocking design allows the parts to be assembled into a functional chair without welding or screws to hold the frame together; a process that takes less than 15 minutes. The interlocking pieces are held together by interconnecting tubes placed in strategic alignment. An analogy would be a Chinese wooden puzzle block that is solid and strong until the key piece is removed, and then the individual pieces come apart easily.

The prototype chair has a solid seat when in use, and yet the frame folds side-to-side to less than 5 inches wide without the wheels. A solid seat provides a stable platform on which to prescribe effective seating components. The foot-rest folds up as in a standard chair; however, the foot-rests swing under the seat for easier transfer without dropping or losing the foot-rest attachment. Rather than repeat the design weakness inherent in the tubular folding "X" frames, the sides are held parallel to each other and perpendicular to the ground by a lower support beneath the seat. The lower support is 8 inches long where it attaches to the side frame. The lower support from each side join in the center to form a "V" in the same plane as the seat. When the seat folds up, the lower support "V" closes. The joining of these two support pieces in the center, form lever arms that keep the two side parallel to each other. This function is important as it keeps loads in the plane of the side piece. This feature will reduce extraneous loads that can cause excessive wear and lead to premature frame failure.

RESULTS

The assembled prototype frame weighed 19.7 lbs., including the foot-rests. The wheels, quick disconnect axles, axle mounting plates, caster mounts, casters and forks and fabric backrest added 6.5 lbs., to bring the total weight, fully rigged, to 26.2 lbs. With the wheels attached, the chair folds to 9 inches wide. The footrests adjust in height by sliding up or down the interconnect tube, and are held in place by a collar. The prototype did not have armrests, although future models will. The handles are molded into the side-piece and ergonomically designed for the proper wrist angle for the pushing or lifting. The prototype chair was made for a small adult with a 16"x 16" seat and a 16" high backrest. The chair has 22" wheels and 8" casters. The main wheel attaches to an axle plate that is adjustable up or down and for or aft. The seat had a built in 10° down slope to the rear. The prototype model will be exhibited at the presentation. The prototype chair was submitted to the Univ. of Pittsburgh wheelchair testing facility in the Highland Drive VA Medical Center on Dec 2, 1999. The prototype chair completed 200,000 cycles on the double drum test. Curb-drop tests were not scheduled to be completed before the submission date of the paper. The test data will be presented as well as an analysis of the results.

DISCUSSION

The prototype chair offers a significant departure from existing wheelchair designs. The design goals of low-cost (under $800 retail price), very lightweight (under 20 lbs.) have been shown to be achievable. The critical factor is durability, and those results will be discussed. The overall goal of using modern engineering design methods of computer-aided-design, computer-aid-manufacturing and Finite-Element-Analysis has been achieved as evidenced by the successful prototype model.

The Phase II proposal plans to make gas-assist injection molds to produce molded components that will be stronger and lighter than the comparable prototype components. Any structural problems identified in the ANSI fatigue tests will be corrected in the Phase II pre-production models. When completed, the Phase II pre-production models will be submitted for complete ANSI testing.

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A KINETIC ANALYSIS OF PROPULSION PATTERNS IN MANUAL WHEELCHAIR USERS

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ABSTRACT
Manual wheelchair users (MWU) are at high risk for repetitive strain injuries to the upper extremities (5). The aim of the study was to determine the applied forces, stroke efficiency, stroke times, and stroke frequency occurring at the pushrim in relation to the stroke pattern utilized by manual wheelchair users (MWU). A sample of 38 male and female-experienced MWU underwent biomechanical testing. Kinetic data were collected at 240 Hz by a 3-D SMART^{Wheel} system and analyzed. The results revealed that the double looping-over-propulsion (DLOP) stroke pattern displayed a significantly higher stoke efficiency, lower stroke frequency, and the greatest tangential force applied in propelling a manual wheelchair compared to the semi-circular (SC), single looping-over-propulsion (SLOP), and arcing (ARC) stroke patterns (6). Understanding biomechanical differences in relation to stroke patterns in MWU may offer insight into both the cause of injury and possibly prevention.

INTRODUCTION
Manual wheelchair users (MWU) have a high prevalence of upper extremity repetitive strain injuries (5). Large peak resultant forces, low stroke efficiency, and high stroke frequency have been shown to be factors that may cause repetitive strain injuries in MWU (1,3). Koontz et al. examined 26 experienced MWU and investigated the forces applied to the pushrim and compared the results to common shoulder injuries. The author's found significant correlations between the magnitude of forces and common shoulder injuries seen by magnetic resonance imaging (bursitis, edema and coracoacromial thickening). Boninger et al. investigated median nerve function and the kinetics of 34 experienced MWU. This study found correlations between stroke frequency and rate of rise of forces applied to the pushrim and mean median sensory amplitude as well as latency.

In our current research we examined the stroke patterns of 43 MWU by analyzing the motion of the 3rd metacarpophalangeal joint and found four different stroke patterns: (arcing (ARC), semi-circular (SC), single looping-over-propulsion (SLOP), and double looping-over-propulsion (DLOP)) (6). Shimada et al. identified similar patterns (SC, SLOP, DLOP) when studying seven-experienced MWU. He noted that the SC stroke pattern had the highest stroke efficiency (0.714 ± 0.035), highest push time (42.12 ± 3.99), and lowest recovery time (57.89 ± 3.99), respectively. The purpose of this study was to determine the relationship between the four stroke patterns we identified and the applied forces, stoke efficiency (SE) and stroke frequency (SF).

METHODS
Subjects. Thirty-eight experienced (11.09 years post operation, SD = 6.09) manual wheelchair users (27 male and 11 female) with spinal cord injuries of T4 level or below volunteered for the study. The mean age of the subjects was 35.14 (SD = 9.34) years (range = 20.69 to 64.65). Informed consent was obtained from each participant prior to the start of the study.
Kinetic Data Collection. A 3-D force sensing pushrim (SMART^{wheel}) was used to measure the three-dimensional forces Fx, Fy, and Fz. These forces were then place in a local coordinate system

consisting of tangential force (Ft), radial force (Fr) and resultant force (F) (1,2). The kinetic data were collected at 240 Hz. The resultant and tangential forces are defined as follows:

$$F = \sqrt{F_x^2 + F_y^2 + F_z^2} = \sqrt{F_t^2 + F_r^2 + F_z^2}$$

$$F_t = M_z + R^{-1}$$

Experimental protocol. Each subject's individual manual wheelchair was fitted with a SMART[Wheel] on both sides and secured onto a dynamometer (7). All of the subjects performed five propulsion trials at two steady state speeds of 0.9 m/s and 1.8 m/s.

Statistical analysis. An Univariate ANOVA with dependant variables of push time (Pt), recovery time (Rt), total time (Tt), SE, SF, Ft, Fr, and resultant force and an independent variable of stroke patterns with a covariant of speeds and sides was used in the analysis of the data. A Scheffe post hoc analysis was performed on significant results. The alpha level was set at ($p < 0.05$).

RESULTS

From the analysis of the SMART[Wheel] data the ARC stroke pattern displayed a significantly lower Pt and Rt, high SF and F with a low SE compared to the other stroke patterns. The SC stroke pattern revealed significantly higher Pt and Rt, low SE, but displayed the lowest F and SF. In addition, the SLOP stroke pattern exhibited a significantly low Pt, Rt, and SE with a high SF and F. Although the DLOP stroke pattern demonstrated a high Pt, Rt, and F, the SE was the highest and the SF was almost as good as the SC pattern. Table 1 lists the mean, standard deviation and significance of the dependant variables as compared to the stroke patterns.

Table 1. The stroke patterns in relation to the mean ± standard deviation stroke times, stroke efficiency (F_t^2/F^2), stroke frequency, and applied forces. A, B, C, and D denotes which stroke patterns are significant in relation to one another.

Dependant Variables	ARC (n=20) A	SC (n=25) B	SLOP (n=62) C	DLOP (n=45) D
Pt (sec)	$0.38 \pm .08^{B**}$	$0.54 \pm 0.14^{ACD**}$	$0.41 \pm 0.10^{B**D*}$	$0.45 \pm 0.10^{B**C*}$
Rt (sec)	$0.35 \pm 0.10^{B*D**}$	$0.50 \pm 0.09^{A*D**}$	$0.45 \pm 0.12^{D**}$	$0.62 \pm 0.23^{ABD**}$
SE (%)	$32 \pm 11^{D*}$	$29 \pm 16^{D**}$	$30 \pm 14^{D**}$	$38 \pm 12^{A*BC**}$
SF (Hz)	$1.43 \pm 0.32^{BCD**}$	$0.99 \pm 0.17^{AC**}$	$1.23 \pm .27^{ABD**}$	$0.99 \pm 0.22^{AC**}$
Ft (N)	$56.64 \pm 27.41^{BD*}$	$42.61 \pm 22.1^{A*D**}$	$51.10 \pm 22.04^{D**}$	$71.60 \pm 25.7^{A*BC**}$
Fr (N)	$80.42 \pm 43.40^{B**}$	$58.82 \pm 15.2^{AC**D*}$	$76.71 \pm 34.35^{B**}$	$72.23 \pm 29.43^{B*}$
F (N)	$96.73 \pm 46.67^{B**}$	$70.48 \pm 17.12^{ACD**}$	$89.48 \pm 36.71^{B**}$	$96.92 \pm 32.02^{B**}$
* = ($p < 0.05$), ** = ($p < 0.01$).				

DISCUSSION

Investigating the magnitude of applied forces, stroke times, stoke efficiency and frequency occurring at the pushrim in MWU may help identify what stroke pattern may lower the risk of common upper extremity injuries (1,3). Shimada et al. found that the SC stroke pattern exhibited the best results with the highest push time, lowest recovery time with the most stroke efficiency when compared to the SLOP and DLOP stroke patterns. These findings were based on only seven MWU.

In determining the stroke pattern differences found among our subjects, we discovered that the DLOP had good biomechanical characteristics. This conclusion is based on the analysis of the DLOP stroke pattern displaying the highest stroke efficiency and the lowest stroke frequency. Although there was a high resultant force associated with the DLOP stroke pattern, this was primarily directed tangentially. Moreover, the DLOP exhibited a significantly longer recovery time period compared to the other stroke patterns. It can be hypothesized that a stroke pattern exhibiting low peak resultant forces, large tangential forces and low stroking frequency may lower the risk of repetitive strain injury to the upper extremity in MWU. Further biomechanical research of MWU pertaining to stoke patterns used needs to be investigated in the future.

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THE FEASIBILITY OF AN ACCELEROMETER-BASED INCLINOMETER TO MEASURE THE ANGULAR ORIENTATION OF A MANUAL WHEELCHAIR WHILE TRAVERSING VARIOUS OBSTACLES

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ABSTRACT

The purpose of this study is to examine the feasibility of using an accelerometer to measure the angular orientation (AO) at the wheelchair/cushion interface during manual wheelchair propulsion (MWP). The AO of the wheelchair measured using an accelerometer was compared to the actual AO measured using a digital level. A filter was used to attempt to separate the accelerations due to changes in AO and those due to vibrations. The use of an accelerometer is not feasible for the measurement of the AO about the medial-lateral axis (i.e. pitch) during MWP. The assumption that the accelerations due to vibrations (e.g. traversing obstacles and cyclic nature of MWP) occur at higher frequencies than changes in AO is not appropriate for MWP.

INTRODUCTION

Vibrations induced during manual wheelchair propulsion (MWP) exceed the comfort and fatigue thresholds cited in the ISO standards on whole-body vibration (1-4). However, the ability of cushions and wheelchairs to reduce the vibration transmitted to the body has not been investigated. In order to accomplish this, the vibrations experienced at the wheelchair / cushion interface (WCI) are compared to the vibrations experienced at the head. This comparison is dependent on the angular orientation (AO) of the vibration sensors (i.e. accelerometers). The AO can be measured by determining the orientation of the accelerometer with respect to gravity. This allows the vibrations measured at the WCI and the head to be transformed from a local (accelerometer) coordinate system to a laboratory coordinate system. The vibrations are due to the wheelchair traversing obstacles and the cyclic nature of MWP. The purpose of this study is to examine the feasibility of an accelerometer to measure the AO at the WCI while measuring the vibration encountered during MWP.

The theory behind using an accelerometer to measure AO is based on the fact that the acceleration due to gravity (1 g or 9.806 m/s^2) is constantly measured. An accelerometer will read 0 g if it is parallel to ground and 1 g if it is perpendicular to ground. Therefore, the orientation of the accelerometer can be calculated using either of the following equations:

$$\theta vert = \cos^{-1}(\text{VertAcc}) \qquad (1)$$

$$\theta horz = \sin^{-1}(\text{HorzAcc}) \qquad (2)$$

where $\theta vert$ is the inclination angle about the medial-lateral axis (a.k.a. pitch) in degrees as a function of the vertical acceleration (VertAcc), $\theta horz$ is the inclination angle about the medial-lateral axis (a.k.a. pitch) in degrees as a function of the horizontal acceleration (HorzAcc), and the accelerations are measured in g's. The assumption is that the accelerations due to vibrations occur at higher frequencies than changes in AO. Therefore, a low-pass filter can be developed to remove the vibrations. If this assumption is true then the accelerometer can be used during MWP to obtain the AO about the medial-lateral axis (a.k.a. pitch). Using the same device for measuring the vibrations as well as the AO would reduce the number of sensors needed and the amount of data collected.

METHODS

One unimpaired individual propelled an Invacare XTR manual wheelchair over nine obstacles (listed in Table I). Three-dimensional acceleration data at the WCI were measured using a triaxial accelerometer (Analog Devices ADXL05, ±4 g) mounted in a seat-plate as described in the ISO 2631 [4]. The acceleration data was filtered using an 8th order Butterworth low-pass digital filter to remove vibrations. Two cut-off frequencies, 1 Hz and 2 Hz, were selected for comparative purposes. Based on equations 1 and 2 the AO of the seat-plate was calculated, providing four measurements of the AO: two based on *VertAcc* and *HorzAcc* filtered at 1 Hz, and two based on *VertAcc* and *HorzAcc* filtered at 2 Hz. The actual AO was measured using a digital level by statically positioning the wheelchair at points of peak inclination and declination. For each of the obstacles the range between the maximum and minimum AO measurement was calculated and compared to the actual values. Plots of the AO versus time for all four measurements were examined to check the sensor's accuracy.

RESULTS

The error between the actual range of the AO and the measured value is minimized by the *VertAcc* data filtered at 2 Hz (Table I). The error is below 3 degrees, however the percent error ranges from 4% to 50%, which is unacceptable. The AO obtained from the data filtered at 1 Hz are typically underestimated, while the inclination angles obtained from the data filtered at 2 Hz are typically overestimated. Figure 1 depicts the measured AO versus time for the first two obstacles with the acceleration data filtered at 2 Hz. The AO is nonzero on the turn between obstacles A and B though it should be zero (Figure 1). Finally, the vibrations due to the cyclic nature of MWP were not removed by the filter at 2 Hz, especially on the flatter obstacles (e.g. A, B, and the turn) (Figure 1).

Table I. Range of AO about the medial-lateral axis (a.k.a. pitch) for each obstacle.

	Range of Seat-Plate Angular Orientation (deg)				
		Cut-off Frequency = 1 Hz		Cut-off Frequency = 2 Hz	
Obstacle	Actual	Vertical	Horizontal	Vertical	Horizontal
A. Rumble Strip	2.5	0.6	2.4	1.8	7.4
B. Ramp	2.5	2.1	6.4	3.3	13.3
C. Curb Drop	7.2	2.6	3.1	8.7	12.0
D. Door Threshold	3.9	1.2	2.0	5.7	2.6
E. Small Sine Bump	7.6	1.4	4.4	7.9	14.0
F. Medium Sine Bump	13.8	1.9	3.1	16.6	19.2
G. Large Sine Bump	21.5	3.9	5.0	18.5	10.9
H. Dimple	2.0	0.4	2.8	1.7	9.5
I. Carpet	2.0	1.4	4.7	3.0	8.2

DISCUSSION

When vibrations are measured at the WCI and at the head using triaxial accelerometers, the vertical, horizontal and transverse accelerations have to be measured relative to a unified coordinate system (e.g. laboratory coordinate system), not individual sensor coordinate systems. The use of an accelerometer is not feasible for the measurement of the AO about the medial-lateral axis (a.k.a. pitch) during MWP. The assumption that the vibrations occur at higher frequencies than changes in AO is not appropriate for MWP. The vibrations, especially those due to the frequency of the strokes, are in the same frequency range as the change in AO. Attempting to filter the data at 1 Hz tended to over-smooth the data, thereby removing events that occurred faster than 1 Hz. Attempting to filter the data at 2 Hz did not adequately remove the effects due to the vibrations, specifically those effects due to the cyclic nature of the MWP (Figure 1).

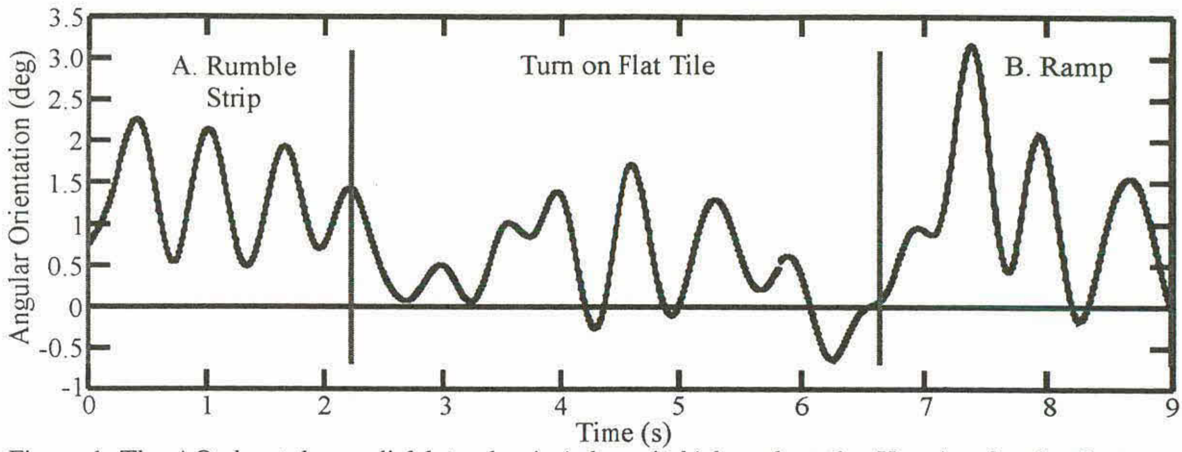

Figure 1. The AO about the medial-lateral axis (a.k.a. pitch) based on the *HorzAcc* for the first two obstacles. Note the cyclic nature of MWP present in the angular orientation measurements.

Due to the inherent characteristics of MWP, specifically vibrations due to traversing obstacles and the cyclic nature, which is in the same frequency range as changes in AO, an accelerometer should not be used to measure the AO of the sensor. Therefore other methods of measuring the AO must be examined since this information is required to perform accurate analyses of whole-body vibration during MWP. A possible solution to this problem could be the use of gyroscopes, which measure the angular velocity rather than angular position and are insensitive to changes in linear acceleration. Without a method to measure the AO of the head and the WCI, accurate analyses of whole-body vibration during MWP cannot be performed.

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NEW WHEELIE AID FOR WHEELCHAIRS: CONTROLLED TRIAL OF SAFETY AND EFFICACY

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ABSTRACT

We tested the hypotheses that those learning to perform aided wheelies (AW) with a new wheelie aid (WA) would be safer than those using the conventional wheelie (CW), that they would be more successful, that they would learn more quickly and that they would find such skills less difficult. We randomly assigned 42 subjects to the two groups and attempted to teach each subject 14 wheelie skills. Overall, although the success rate was not significantly greater, the AW subjects' safety scores were higher ($p<0.0001$), they required less time to learn the skills ($p=0.002$) and they found the skills to be less difficult ($p<0.0001$). Learning to perform AW with the new WA is safer, faster and less difficult than learning conventional wheelies.

BACKGROUND

The "wheelie" is a useful skill that enables the wheelchair user to overcome a number of environmental obstacles (1-3). The inability of most wheelchair users to perform wheelies, the lack of an existing wheelie aid suitable for use on an on-going basis and the limited maneuverability afforded by conventional antitip devices provided the incentive for designing a new wheelie aid (WA)(4,5) that permits wheelie-like function (Figure 1). Unlike current antitip devices and previously reported wheelie aids, the new WA design is out of the way during normal wheelchair use but self-deploys when needed, making it suitable for long-term use.

RESEARCH QUESTIONS

The purpose of this study was to evaluate the safety and efficacy of the new WA device. Specifically, we tested the hypotheses that those learning to perform aided wheelies (AW) with a new wheelie aid (WA) would i) be safer than those using the conventional wheelie (CW), ii) that they would be more successful at learning the skills, iii) that they would learn more quickly and iv) that they would find such skills less difficult.

METHODS

We randomly assigned 42 subjects to the CW and AW groups and attempted to teach each subject 14 wheelie skills -- wheelie rest, thresholds (stationary method), thresholds (momentum method), stationary wheelie, move forward, soft surfaces, gravel, curb ascent (stationary method), curb ascent (momentum method), turn in place, turn corner, incline descent, curb descent and move backwards. We recorded the success at learning each skill and the duration of the training sessions (in 5-minute increments). Subjects scored the difficulty level on a 5-point Likert scale. The trainer used visual analog scales (VAS) to quantify safety during each skill. To compare the percentage of subjects who were successful, we used Fisher's Exact Test. We used two-sample t tests to compare the CW and AW groups from the standpoint of safety, time needed and the difficulty. We made a Bonferroni adjustment in the p value (to 0.0036) used to define statistical significance.

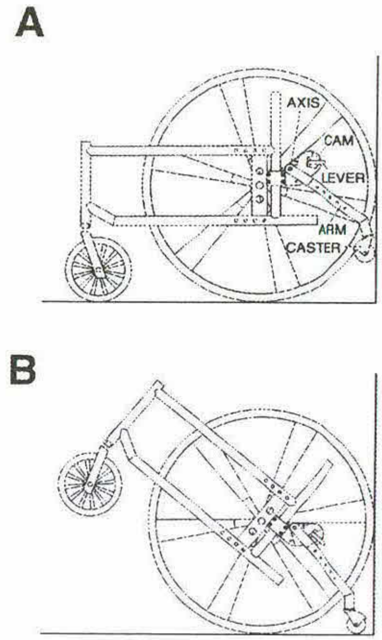

Figure 1. The new wheelie aid (WA) attached to a wheelchair. **A.** In the resting position, the rearmost aspect of the WA does not extend behind the rearmost aspect of the rear wheel. **B.** When the wheelchair tips back far enough for the WA caster to contact the ground, the force of the tipping wheelchair causes the WA arm to move through an arc to the deployed position.

RESULTS

There were no injuries in either group. The overall results are shown in Table 1.

Table 1. Overall Safety, Percent Success Rate, Time Taken and Difficulty

Parameter	Conventional Wheelie			Aided Wheelie			p
	n	mean	SD	n	mean	SD	
Safety (%)	14	43	27	14	98	2	<0.0001
Success (%)	292	92.8	--	265	96.2	--	0.079
Mean Time Taken (x5 min)	23	1.56	1.08	19	0.72	0.35	0.0022
Difficulty (1-5)	20	2.94	0.38	19	2.23	0.34	<0.0001

n = number of subjects, SD = standard deviation

DISCUSSION

Although there was no statistically significant difference between the CW and AW groups in the proportion of subjects who were successful at learning the skills, this was probably due to a ceiling effect -- excepting the curb ascent skills, almost all of the subjects in both groups were successful at all skills. Differences between the groups may be more easily demonstrated among older and more disabled subjects, those who traditionally have not been able to perform wheelie skills. Nevertheless, overall, the AW skills were safer than the CW skills, were learned more quickly and were perceived to be less difficult. The exception was the "gravel" skill which, as expected, was more difficult for the AW group because the WA casters sunk into the gravel.

There are some potential savings from use of the WA, including less treatment time to learn the skills, and less need for an attendant to assist in handling obstacles in the community. Also, to the extent that WA users realize improved safety with the use of WAs, there may be savings related to the prevention of injury. We believe that more wheelchair users should have the opportunity to acquire wheelie skills. Also able-bodied clinicians who are involved in wheelchair provision and training should take the time to learn these wheelie skills so that they will be better able to advise the wheelchair users with whom they work and better able to teach these skills. Future studies are needed, including a longer-term study on the safety and effectiveness of the WA in the community and studies to determine how different impairments affect the ability to learn AW skills. In conclusion, the new wheelie aid provides stability and wheelie-like function without interfering with maneuverability. Learning to perform aided wheelies is generally safer, faster and less difficult than learning conventional wheelies.

ACKNOWLEDGEMENTS
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KINEMATIC COMPARISON OF HYBRID TEST DUMMY TO WHEELCHAIR OCCUPANT

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ABSTRACT

Anthropometric and Hybrid test dummies provide a safe alternative to human subjects when investigating mechanisms of wheelchair tips and falls. The data researchers acquire from these test dummies is more valid if the test dummy represents the population being studied. The goal of this study is to prove the validity of a Hybrid II test dummy (HTD) as an accurate representation of a wheelchair user. The HTD and wheelchair user had similar trunk stability characteristics during kill switch and full reverse braking conditions. However, the test dummy underestimates the motion and hence severity of falls during the less extreme joystick braking. This illustrates the need for development of a low speed, low impact test dummy that emulates the wheelchair user population.

BACKGROUND

At any given time, there are approximately 1.5 - 2 million full-time wheelchair users in the United States. This number is greater when considering part-time users. Data collected by Calder, et al. report that there are about 36,000 serious wheelchair accidents annually, a strong majority of which are attributable to tips and falls(1).

Due to the nature of the observed problem, it is not always practical or ethical to use actual wheelchair users to assess the risks and prevention mechanisms of tips and falls. Test dummies provide a safer alternative. The Hybrid and ATD series of test dummies developed by General Motors are industry standards in vehicle crash testing. These test dummies have been proven to be very repeatable, reproducible, durable, and serviceable test devices. Because of this, they have been utilized in other applications such as assessment of wheelchair safety characteristics. Kirby used a Hybrid II test dummy to study the effects of locking the brakes in rearward tipping accidents(2). Sosner utilized a 50th percentile Hybrid III dummy and depot-type wheelchair to simulate three types of curb negotiation accidents(3). Fast employed a Hybrid III in studying the effect of restraining systems (lap belt and four-point restraint) on curb negotiation accidents(4). Cooper et al. used a 50th percentile Hybrid II to examine the safety of 8 power wheelchairs during braking(5). The data researchers acquire from these test dummies is more valid if the test dummy represents the population being studied.

The goal of this study was to prove the validity of a Hybrid II test dummy as an accurate representation of a wheelchair user. An accurate dummy will enhance understanding of how the user, wheelchair, and environment interact, and may lead to greater mobility and less risk of injury.

METHODS

This study used data from Cooper et al(5). A 50th percentile Hybrid II crash test dummy was used to simulate the occupant of a power wheelchair. The bladder of the dummy was removed to reduce trunk resistance and bolts at the joints were loosened and lubricated to decrease lower extremity joint stiffness. A single wheelchair user with T8 paraplegia due to traumatic spinal cord injury served as a basis for validation.

Both the HTD and test subject were outfitted with black clothing and passive reflective markers were fixed to nine anatomical positions to capture the motion (see figure). The HTD was seated in the test wheelchair according to the procedure described in ISO 7176-08 draft standard. The subject was seated with arms adducted and elbows bent in 90+ degrees of flexion to prevent using them for support. Two spotters were positioned approximately 3 feet beyond the braking line to intervene in case of falls.

Comparison was performed using one power wheelchair: a Quickie P110, Sunrise Medical Incorporated. Reflective markers were placed on six areas of the left side, characterizing the wheelchair setup (see Figure).

The filming was performed in the test laboratory hallway. A Panasonic Digital 5100 camera and a Panasonic AG-7400 VCR were used to film the testing of the wheelchair. Data were collected at 30 frames per second with a shutter speed of 1/500 second. The film was digitized using a Peak Performance analysis system at 60 frames per second and conditioned with a low-pass butterworth filter at a 6 Hz cutoff frequency.

Test protocol included three braking conditions: kill switch activation, joystick release, and full reverse of the joystick. One test operator, dressed entirely in black clothing, drove the wheelchair from the right side without obscuring the markers. A twenty foot run-up area before the filming area was used to achieve maximum speed of the wheelchair. A braking line was marked on the floor, perpendicular to the line of motion. The front caster was used as a visual reference for initiating the braking condition. Videotape later revealed the precise location where braking occurred.

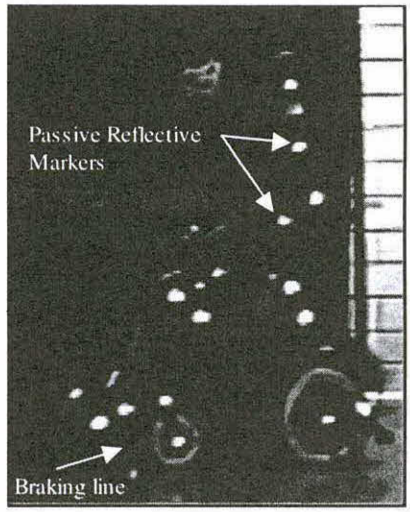

Figure showing test trial

RESULTS

The distance the wheelchair occupant slid in the seat, the head excursion in relation to the top of the backrest, and the trunk angular displacement, velocity, and acceleration were used as measures of comparison between the subject and HTD. Statistical analysis was performed using unpaired two-sample t-tests. No significant differences were found ($\alpha<.05$) in the power wheelchair braking distance and time, speed at which braking occurred, average and maximum velocity, and maximum acceleration within trials between the HTD and the human occupant with exception of the maximum velocity during full reverse braking. Significant differences existed between the HTD and human occupant's trunk angular displacement and acceleration, and relative head excursion during joystick release braking conditions. There were no other statistical differences; however, the trunk angular velocity of the wheelchair user was consistently higher in joystick release braking trials.

Joystick Release Braking only	Wheelchair User		HTD		P value
Trunk angular displacement (°)	59.48	(.67)	29.92	(4.26)	.007
Trunk angular velocity (°/s)	96.95	(14.35)	28.47	(4.91)	.098
Trunk angular acceleration (°/s^2)	2027	(123)	533	(112)	.005
Relative head excursion (m)	.627	(.061)	.327	(.085)	.019
Sliding distance (m)	.014	(.014)	0	(0)	.389

DISCUSSION

Lack of statistical significance between trials ensures that differences in HTD/human motion are attributable to different mechanics/anthropometrics and not the input from the power wheelchair. Differences in the maximum velocity of the wheelchair during the full reverse trials do not discourage this notion since in all cases, the maximum velocity occurred before braking was initiated and the speed at the instant of braking was not significantly different.

What is of most interest is the comparison in trunk stability of the HTD and a typical wheelchair user. Many wheelchair users have decreased muscle tone and control in the abdomen and lower back and therefore may have difficulty maintaining upright, seated posture. The wheelchair user and HTD exhibited similar trunk stability characteristics during kill switch and full reverse braking conditions. Differences were found in the trunk angular displacement and acceleration and the relative head excursion during joystick release braking conditions. This braking condition imparts lower deceleration forces than the other two braking conditions. Static friction and trunk stiffness may account for the differences occurring at the lower deceleration. At low decelerations, the frictional force may oppose the disturbing force and prevent or reduce trunk motion. At any rate, the HTD appears to match or underestimate the severity of occupant excursion during braking trials. This means that any results obtained from testing with the dummy would likely occur in the wheelchair user.

Future studies will focus on recruiting a larger sample with matched anthropometrics of the wheelchair user and HTD. Other areas of research include computer modeling to predict the outcomes of wheelchair driving accidents and the development of a test dummy that emulates a person with a spinal cord injury. Currently, no low speed, low impact dummy exists for wheelchair crash studies. A reliable and accurate dummy is necessary for valid results and ultimately the reduction in accident frequency and severity.

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EFFECT OF WHEELCHAIR SEATING STIFFNESS ON OCCUPANT CRASH KINEMATICS AND SUBMARINING RISK USING COMPUTER SIMULATION

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ABSTRACT

Many wheelchair users must travel in motor vehicles while seated in their wheelchairs. The characteristics wheelchair seating systems play a key role in the protection of their occupants in a crash. Seating systems properties such as strength, stiffness and energy absorbance have been shown to have significant influence on risk of submarining. This study utilizes computer crash simulation to explore the effects of seat surface stiffness on wheelchair occupant kinematics characterizing submarining in a frontal crash. Results indicate that wheelchair seating stiffness does influence occupant kinematics associated with the risk of submarining. Softer seat surfaces were found to produce pelvis excursion trajectories associated with increased submarining risk. Application and evaluation of the ANSI/RESNA WC-19 submarining/seat integrity test criterion indicates that increased submarining risk that may occur without seat failure could go undetected.

INTRODUCTION

Motor vehicles seat designs incorporate numerous features which protect an occupant in a crash. Seating system strength, stiffness and energy absorbance have been shown to have a direct impact on occupant crash kinematics, and in particular on submarining risk [1]. *Submarining* is characterized by the pelvic restraint slipping upward over the iliac crests and loading the soft abdominal tissues. Submarining can potentially lead to severe internal injuries of organs in the abdominal region [2]. Previous motor vehicle research has shown that motion sequence of the pelvis during a crash can be correlated with risk of submarining [1,3]. Accordingly, kinematic analysis techniques have been used to compare and optimize automotive seating system designs. With the exception of Kang and Shaw's study on wheelchair seated posture, to-date little research has been done to evaluate the influence of wheelchair seating system design on injury risk [4].

Submarining risk can be assessed through evaluation of forward and vertical crash motion sequence of the pelvis. In particular, the vertical downward excursion of the pelvis during a crash which permits the lap belt to slip upward onto the abdomen has been shown to be associated with increased levels of submarining risk [1]. Seat surface stiffness is one parameter which can effect pelvis excursion.

The eminent ANSI/RESNA WC-19 Wheelchairs Used as Motor Vehicle Seats Standard will evaluate complete wheelchair systems, including their manufacturer-provided seating system, using a 20g/30mph frontal sled impact test. As a means to evaluate seating surface crash integrity, compliance with WC-19 requires that the pre- to post-test change in H-point (hip) vertical position not exceed 20%. The intent of this test criterion is to assure that failure of the seat surface or seat attachment hardware has not occurred as a result of the test. However, it is important to note that submarining may occur without seat failure. This scenario may escape detection by WC-19 test criterion.

RESEARCH QUESTION

Does wheelchair seating surface stiffness influence occupant H-point excursion and submarining risk in a frontal motor vehicle crash?

METHODS

Utilizing a previously developed and validated computer crash simulation model of a commercial wheelchair, a parametric sensitivity analysis was conducted to investigate the effect of seat stiffness on lower torso (pelvis) excursion in a frontal crash [5]. The validated model consisted of a powerbase wheelchair, secured using 4-point belt-type tiedowns and a 50th percentile Hybrid III anthropomorphic test device, restrained with a 3-point occupant restraint system. The shoulder belt was mounted to the vehicle and the lap belt was anchored to the wheelchair. The wheelchair and occupant system was subjected to an SAE J2249-compliant 20g/30mph frontal sled impact pulse.

To investigate the influence of seating surface stiffness, a parametric sensitivity analysis was conducted, varying the original seat stiffness from 25% to 200% in increments of 25% while maintaining all other conditions constant (Figure 1). For each stiffness scenario occupant pelvis excursion, characterized by the H-point, or hip joint, was recorded. The original seating system used in the model was a rigid phenolic seat pan and foam cushion having a 667 lb/in midrange stiffness (denoted as 100%). Force-deformation curves used to depict seat surface stiffness are shown in Figure 1. These stiffness ranges were found to correlate with those of commercial wheelchair seating support surfaces evaluated in our laboratory [6].

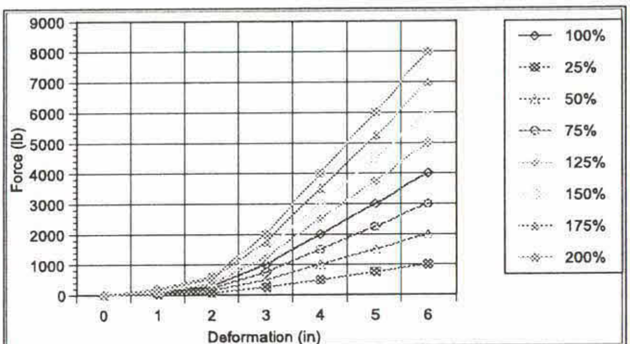

Figure 1 – Seat Stiffness Scenarios Evaluated in Parametric Analysis

RESULTS

As expected, H-point peak vertical excursions show an increasing trend with softer, i.e. less stiff, surfaces (Table 1). H-point vertical motion was also characterized using the following methods; (i) % difference between pre- and post-test, (ii) % difference between pre-test and peak vertical excursion, and (iii) peak vertical excursion/H-pt vertical excursion limit recommended by Viano and Arepally. The first method assesses compliance with the ANSI/RESNA WC-19 test criterion which limits pre- to post-test H-point position to 20%. Figure 2 provides H-pt trajectories for mid-point (100%) and end-point (25% and 200%) stiffness scenarios.

Table 1 - Hybrid III ATD H-point Kinematics

Seat Surface Stiffness	Peak $H\text{-}PT_{vert}$	Peak $H\text{-}PT_{hori}$	(a)% Diff pre- to post-test $H\text{-}PT_{vert}$	% Diff pre-test to peak $H\text{-}PT_{vert}$	Peak $H\text{-}PT_{vert}$/ Viano limit(b)
25% (softer)	-2.45	4.32	12%	22%	1.24
50%	-2.18	4.03	7%	20%	1.11
75%	-1.99	3.85	2%	18%	1
100%	-1.86	3.70	-1%	17%	0.94
125%	-1.79	3.60	0%	16%	0.91
150%	-1.66	3.53	-4%	15%	0.84
175%	-1.57	3.43	-5%	14%	0.79
200% (firmer)	-1.69	3.56	-8%	15%	0.86

[a] ANSI/RESNA WC-19 Test Criterion. For simulations post-test set to 120 msec. Negative % values denote a vertically higher position at t =120 msec.
[b] $H\text{-}PT_{vert}$ limit recommended by Viano and Arepally = 1.97 in. Values greater than 1.0 exceed limit.

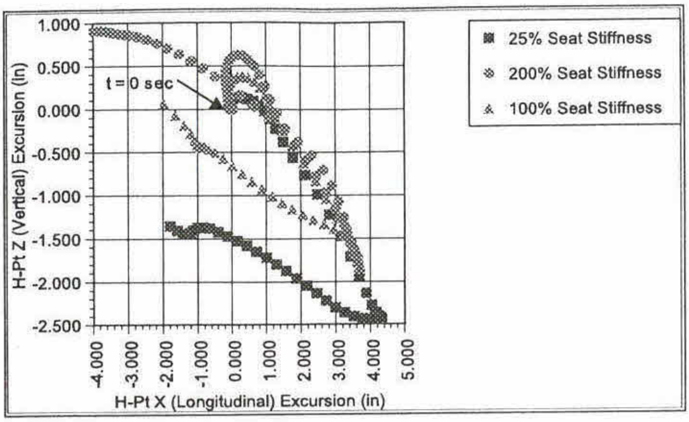

Figure 2 – Wheelchair Occupant (ATD) H-Pt Excursion Trajectories for 25%, 100% and 200% Seat Stiffness Scenarios: 0 to 120 msec

CONCLUSIONS

This sensitivity analysis indicates that seat surface stiffness does influence wheelchair-seated ATD H-pt kinematics during a frontal impact. Accordingly, it is also reasonable to expect that wheelchair seat surface stiffness will influence the risk of submarining. Seat stiffness scenarios which represent softer seats appear to present the greatest risk of submarining. These stiffness scenarios coincide with those found in sling type wheelchair seating systems. Our analysis also shows that the ANSI/RESNA WC-19 test criterion for submarining/seat integrity may fail to identify submarining risk which may be present without seat failure. The results of this study also indicate a need for wheelchair seating system manufacturers to begin to evaluate "anti-submarining" strategies such as those used in the automotive seating industry.

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Evaluation of Wheelchair Seating System Crashworthiness – Wheelchair Back Surfaces and Attachment Hardware

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Abstract

Automotive seats are tested for compliance with federal motor vehicle safety standards (FMVSS) to assure safety during impact. Many wheelchair users rely upon their wheelchairs to serve as vehicle seats. However, the crashworthiness of these wheelchairs during the impacts is often unknown. This study evaluated the crashworthiness of five Wheelchair Seating Systems (WCSS) back surfaces and attachment hardware using a static test procedure simulating crash loading conditions. The crashworthiness was tested applying a rearward load to each seating system at the center of gravity of the reference loader gauge. The magnitude of the applied loads was established through computer simulation and biodynamic calculations. None of the five tested WCSS withstood the simulated crash forces. All failures were associated with attachment hardware.

Background

Manufacturers of automotive seats are required to perform extensive testing to assure that their production vehicle meets government crashworthiness and occupant protection regulations as described by FMVSS (1). Seats and hardware have to withstand certain loads during a crash and must provide support for the occupant under impact loading and during rebound. Wheelchair users who cannot transfer to vehicle seats use their wheelchairs as vehicle seats while they travel. However, the level of protection that wheelchair seating systems provide under impact is, in many cases, unknown. Although ANSI/RESNA WC-19 evaluates wheelchair crashworthiness, substitute seating systems are often added as after-market products and will not be sled tested (2). A typical WCSS consists of a separate seat and back surface with cushions mounted onto the wheelchair frame using attachment hardware (see Figure 1). The integrity of supporting surfaces and attachment hardware must be maintained during a crash. Therefore, a test to evaluate and predict wheelchair seating surface and attachment hardware crashworthiness, independent of the wheelchair frame, would be useful for seating system manufacturers. This study proposes a static test method and applies this method to evaluate five commercial wheelchair seat backs and their associated attachment hardware: Jay2 Deep Contour Back, Jay2 Back Tall, Jay Fit Back System, Personal Back, and Sit Rite Back.

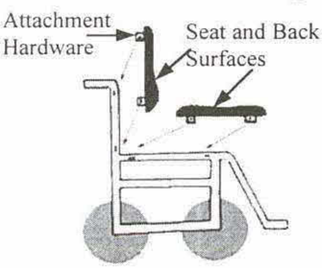

Figure 1
Common WCSS Configuration

Research Question

Do commercially available wheelchair seat backs and their associated attachment hardware withstand loads encountered in a motor vehicle crash?

Method

Two loading conditions which wheelchair seat backs may be exposed to are rebound loads associated with frontal impacts, and loads encountered during rear impacts. In determining the target test load, the worse case loading scenario between two conditions was chosen.

Rear impact loads were derived following FMVSS 207 test criterion which applies a 20g static load to seating systems. Accordingly, rear impact loading was calculated as 20 x (weight of the upper torso of a 50th percentile male + weight of each WC seat back). The equivalent calculated rear impact load of each seat back was approximately 2400 lb. Rebound loads associated with frontal impact were determined from computer crash simulations. Maximum seat back loading associated with rebound of a 50th percentile male was approximately 2280 lb.

The **target loading** for the test was based upon rear impact conditions, or the worse case scenario, which was **2400 lb**.

A rigid test fixture was developed to mount the wheelchair back surface (WCBS) with attachment hardware (AH) to the Instron testing machine (see Figure 2). Two solid rods of the test fixture simulated the wheelchair back vertical support members: rods were 18" apart and each rod had a 1" diameter. The loads applied to the WCBS and AH were generated using the Instron Series 4204 loading machine, which is designed to test materials in either tension or compression. Loads were transmitted to the seat backs using the upper torso (back) unit of the ISO 7176-07 test dummy, a reference loader gage (RLG), which was "designed to simulate the dimensions and mass distribution of the human body" (Figure 3) (3). The following steps were implemented (see Figure 4):

1. A back surface was mounted to the rods of the test fixture with manufacture-provided hardware.
2. The back unit of the RLG, representing the upper torso, was placed on top of the surface.
3. A downward force was applied to the back unit of RLG at the center of gravity of the RLG (CGRLG).

The load characteristics were as follows:

- Apply load at 20 in/min Instron machine cross head speed.
- Hold load for 5 seconds at 2400 lb.
- Release load at 20 in/min.

The target force and cross head speed were programmed into the Instron computer. Instron cross head position and the applied load were recorded during the test.

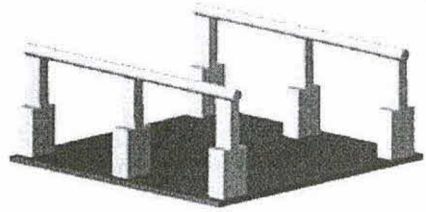

Figure 2 Surrogate wheelchair frame test fixture

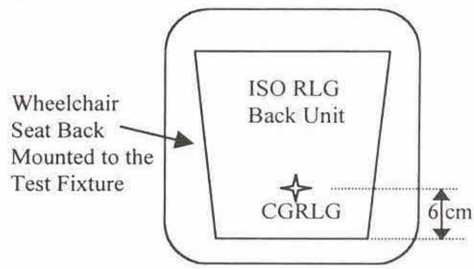

Figure 3 Top view of the load application point on the ISO Back Unit

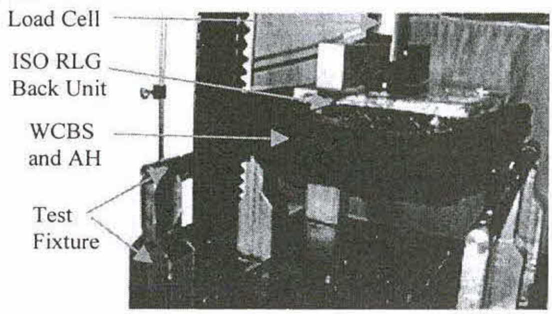

Figure 4 Test set up

RESULTS

Table 2 shows the main reason of failure of each WCBS and AH. All five wheelchair seat backs failed to withstand the target force because of attachment hardware failure. Figure 5 shows the load versus deflection curves of the five tested wheelchair backs. The load that each WCBS and AH withstood is shown in Figure 5: "X"s on the graph indicate the failure points. Four out of five tested seat backs failed at a force less than 50% of the targeted force of 2400 lb. The J2 Tall withstood the highest load, 1468.2 lb, and the Personal Back failed at the lowest load, 401.8 lb.

Table 2 Results of WCBS and AH testing

Manufacturer	Test Seat Back	Failure Description
Sunrise Medical	J2 Deep Contour	upper hardware : severe deformation lower hardware : released from retention slot
Sunrise Medical	J2 Back Tall	upper hardware : severe deformation lower hardware : released from retention slot
Sunrise Medical	Jay Fit Back	lower hardware : both side pins released from retention slots
Invacare	Personal Back	lower hardware : plastic part of the hardware fractured and released from retention slot
Metro Medical	Sit-Rite	all four pieces of hardware deformed; lower hardware slipped free

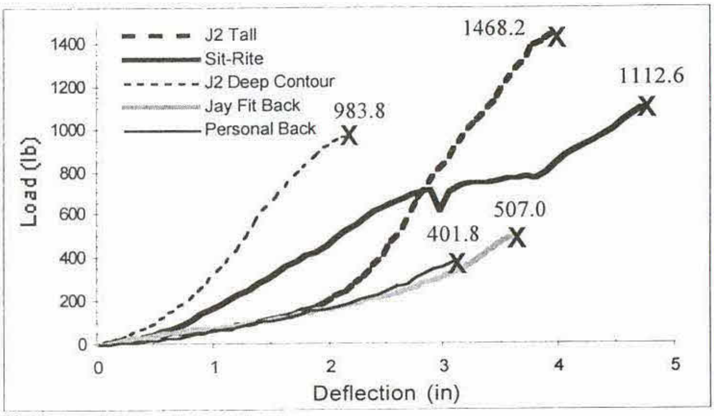

Figure 5
Load vs. Deflection of tested seat backs – "X" indicates failure

CONCLUSIONS

The results of this study show that none of the tested commercially available wheelchair seat backs and their attachment hardware withstood the forces that may be encountered during a rear impact or rebound associated with frontal impact. While compliance with this low cost static load test would not necessarily imply a crash proof WCSS, it does serve as a first step towards evaluating WCSS safety for use on wheelchairs used as motor vehicle seats. Future work will focus on validating the proposed static test methods to assure dynamic impact test similarity. Additional efforts will seek to evaluate more wheelchair seating components.

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EVALUATION OF THE SEAT BELT ANCHORAGE STRENGTH OF A PROTOTYPE WHEELCHAIR INTEGRATED OCCUPANT RESTRAINT SYSTEM

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ABSTRACT

Seat integrated occupant restraint systems used in automotive applications have shown improved occupant safety and a decreased risk of injury during motor vehicle impacts. Research is being done to study the feasibility of seat-integrated occupant restraint technology in the wheelchair industry. Previous studies using crash simulation software have shown an increase in wheelchair occupant crash protection when using a wheelchair occupant integrated restraint system (WIRS) versus a vehicle mounted wheelchair occupant restraint systems. In this study a solid model WIRS assembly was designed and analyzed using Finite Element Analysis (FEA). The seat belt strength of a WIRS prototype was evaluated using the FMVSS 210 protocol. Loads and deformation on the WIRS prototype were measured as a result of an applied static load of 3000 lb. on both shoulder and pelvic belt anchorage points. No rupture or failure of the integrated restraint system (IRS) or the wheelchair seat frame occurred.

INTRODUCTION

Automotive industry studies show that belt anchorage points of occupant restraint systems (ORS) mounted to the seat, as opposed to the car structure, improve belt fit and decrease the risk of occupant injury during motor vehicle impacts in forward, rearward and rollover direction [1,2]. Besides testing the seat to back strength of the seat according to Federal Motor Vehicle Safety Standard (FMVSS) 207 for seating systems [3], the protocol of FMVSS 210 for seat belt anchorage strength is developed and used to evaluate the strength of these integrated ORS [4]. Presently a growing number of wheelchair users rely on motor vehicles as their primary means of transportation. Since individuals who use power wheelchairs are often not able to transfer, their wheelchair is secured to the vehicle floor and the wheelchair seat functions as a motor vehicle seat. Typically fixed shoulder belt anchor points of current ORS in motor vehicles follow installation for a 50th percentile male user according to SAE J2249 WTORS guidelines [5]. Authors previous research has shown that current installed ORS with fixed vehicle-mounted anchor points used for a various sized population result in significantly different torso belt angles from those recommended by SAE J2249 WTORS [6]. A computer simulated 20g/30mph frontal crash, using a wheelchair-seated 50th percentile male Hybrid III test dummy, was recently developed to study the effects of occupant restraint configuration and anchorage location [7]. Results showed minimized occupant excursion, reduced torso rotation and minimized injury criteria indices when using a WIRS as compared to fixed vehicle-mounted ORS configurations.

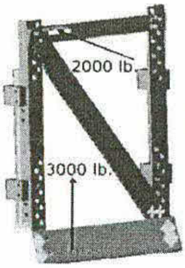
RESEARCH QUESTION

Does the developed prototype WIRS comply with FMVSS 210 for seat belt anchorage strength.

METHODS

The Tarsys seat frame of an adult automatic recline wheelchair, manufactured by Invacare, was first successfully tested for its seat to back strength and frame anchorage hardware integrity using the FMVSS 207 test protocol for seating systems [8]. Pro-Engineer and Solid-Works were used to construct the WIRS assembly. FEA (Pro-Mechanica and Working Model-FEA) was used to calculate and analyze the stress concentration and deformation of the WIRS assembly.

A static load of 2000 lb. was applied in forward direction on the upper horizontal structure and a load of 3000 lb. was applied in upward direction on the lower horizontal structure of the WIRS model (see Figure 1). This simulates the reaction force of the occupant restraint on the WIRS structure in a forward crash. Upon acceptable FEA results, a prototype of the integrated restraint system (IRS) was build and mounted onto the back of a Tarsys seat frame (see Figure 2).



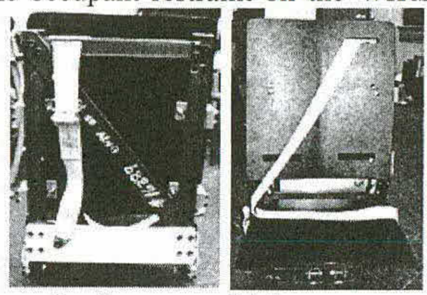


Figure 1 (left): FEA model of the WIRS.
Figure 2 (center/right): Prototype WIRS mounted on a Tarsys wheelchair seat frame.

The FMVSS 210 protocol to test the seat belt anchorage strength of motor vehicle seats was modified and used as a guideline to statically test and evaluate the WIRS prototype. The WIRS prototype was mounted onto a rigid test fixture on an Instron 4204 loading instrument. Two standardized body blocks resembling the torso and abdominal area of a 50^{th} percentile male were secured with the WIRS and attached to the Instron cross-head (see Figure 3). Load cells between the body block attachment points and the Instron cross-head measure the applied loads onto the pelvic and shoulder body blocks. With a speed of 20in./min. of the Instron cross-head, a pre-load of 600 lb. was applied (300 lb. for the torso and 300 for the pelvic body block) after which the load was increased to 6000 lb. (3000 lb. for the torso and 3000 lb. for the pelvic body block). Data from the body block connected load cells was acquired at 4 Hz. using Virtual Bench. To monitor the permanent deformation of the WIRS, the angle of the Tarsys seat back was recorded before and after the load test using an inclinometer.

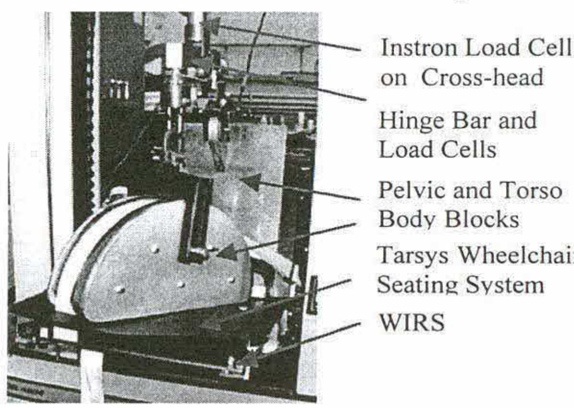
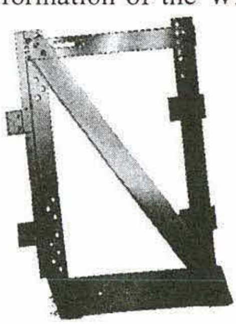


Figure 3: Setup of the prototype WIRS on the Instron machine to test the seat belt anchorage strength.

RESULTS

<u>FEA analysis</u>: The FEA analysis showed an acceptable maximum stress concentration and deformation of the WIRS model (see Figure 4 and 5). The maximum deformation of the upper WIRS had a magnitude of 0.61 in. whereas the stress concentration had a magnitude of 60000 ksi.



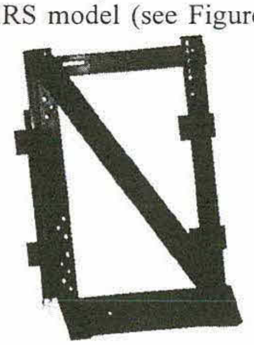


Figure 4 (left): Maximum deformation of 0.61 in. on the WIRS FEA model.
Figure 5 (right): Maximum stress concentration of 60000 ksi. on the WIRS FEA model.

FMVSS 210 testing: The pre-load data collected at 10% of the maximum load (300 lb.) was reached for both pelvic and torso body block. After reaching the 300 lb. for each body block the load on the Instron machine was increased to 6000 lb. A maximum load of 5400 lb. was measured for the torso body block load cell and a maximum load of 1489 lb. was measured for the pelvic body block load cell (see Figure 6). The difference in angle of the Tarsys seat back before and after loading the WIRS structure was 10°. After releasing the load on the WIRS prototype the complete WIRS structure and attachment hardware were inspected for damage. No damage or rupture of the IRS or wheelchair seat frame were found.

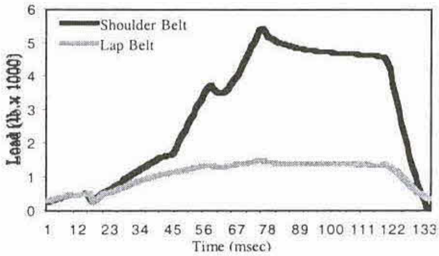


Figure 6: Maximum load on pelvic and shoulder belt anchorage points.

DISCUSSION AND CONCLUSION

FEA data showed sufficient strength of the WIRS model and the WIRS prototype appears to be able to withstand crash-level loads of 5400 lb. without hazardous failure. Load cell data showed a difference in load applied to the torso and the pelvic block and the required load of 3000 lb. was not evaluated for the pelvic block. An SAE J2249 20g/30mph sled test will be conducted next to evaluate the effect of dynamic loading of the WIRS prototype. After dynamic testing of the WIRS prototype, design criteria will be refined for use in the development of a safe and effective wheelchair occupant restraint system. This prototype evaluation demonstrates the feasibility of integrated restraint technology as applied to wheelchair transportation.

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DEVELOPMENT AND FABRICATION OF AN ANTERIOR HEADREST FOR A WOMAN WITH ALS

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Suzanne Miller, BA

ABSTRACT
This case study demonstrates the development and modification of and anterior headrest support for a woman with Amyotrophic Lateral Sclerosis who displays severe shortening of the anterior structures of the neck. This headrest was designed to provide support and also allow her to interact with and observe the world around her. Several attempts were needed to find a system that would provide support and yet could be easily adjusted by caregivers.

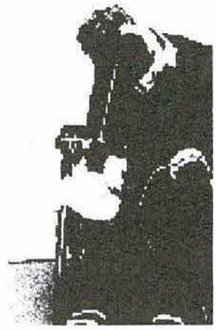
BACKGROUND
Sarah, a 51-year-old woman with Amyotrophic Lateral Sclerosis (ALS), and her family requested an evaluation at University Hospital School for positioning. She requires total assistance to complete her self-cares. She has minimal muscle strength in her neck and severe neck contractures. She prefers to posture with her head/neck flexed forward due to weakness and difficulty swallowing with neck extension. Following an evaluation by the occupational and physical therapists, an Action Tilt-in-space wheelchair with Silhouette cushions, to provide pressure relief was decided upon and ordered.

Although still able to speak, Sarah does so with extreme difficulty and is not easily understood. Sarah uses a Dynamyte to communicate her needs to others. A scanning switch to activate the device is placed between her knees. The tilt-in-space chair did provide some improvement, allowing Sarah to have slightly better visual access to her communication device as well as her surroundings, but it did not provide sufficient anterior head/neck support.

APPROACH ONE
During the evaluation it became apparent that normal head supports would not be effective and neck collars were too obstructive to her swallowing. Tilting the wheelchair made it clumsy to handle and difficult to maneuver. Sarah requested help to devise a support for her head. This process took several attempts and resulted in two different designs, which were fabricated by the Rehab Engineering department.

ANTERIOR HEADREST

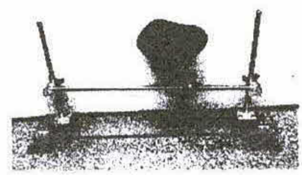
DESIGN ONE



The first design was done immediately after Sarah was positioned in her new wheelchair. We attempted to support her head anteriorly, with a forehead support mounted off the wheelchair arm tubing.

A Whitmeyer Plush pad with an extra inch of Sunmate foam inserted in side the covering was attached to a long ball/rod extension that was inserted into a long multi-angle adjustable rod. This rod was attached to a Miller push button swing away bracket that was clamped to the armrest tubing. This allowed the support to swing away during transfers.

APPROACH TWO

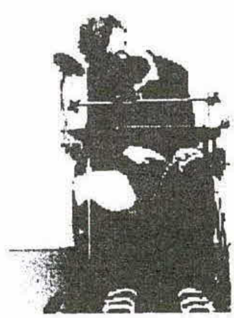


After a trial period, Sarah returned and shared her concerns. The headrest was a little too high, was difficult for caregivers to adjust and Sarah was experiencing redness and discomfort on her forehead from the pad after short periods of time. This design, though fairly effective, was difficult for the caregivers to keep aligned because Sarah is positioned slightly differently every time she seated in her wheelchair.

Rather than adjust Sarah's position, caregivers attempted to readjust the bracket each time, which quickly resulted in total frustration. Another significant concern was the development of a pressure sore on her right clavicle. This occurred secondary to her preferred neck position, which caused pressure and moisture build up in the area.

After discussion and brainstorming, a second design was fabricated. Lack of flexibility to adjust the headrest appeared to be the major concern of the first designed. The new design used the armrests for support, could be positioned at the forehead or the cheek and afforded flexibility to move the headrest in an anterior or posterior direction, left or right, up or down or to rotate it.

DESIGN TWO



A small polycarbonate platform that stretched across the seat of the chair was attached to the armrests with clamps. Clear polycarbonate was chosen so that this piece would not obstruct more of Sarah's vision. A mounting plate was welded to the ends of two twelve-inch lengths of ½ inch steel rods. These rods were mounted vertically on the platform at the opposing ends. Using Zygo X-joints, another ½ steel rod was attached horizontally to the vertical rods across the platform. This allowed for vertical movement of the support.

The head pad was attached to the horizontal bar by using a third Zygo X-joint. This Whitmeyer Plush pad attached to a 6-inch ball/rod. The rod was inserted into the X joint. This design allowed the pad to be moved horizontally and vertically and to be rotated simply by using knobs to loosen and tighten the clamps in position. In addition, a Polartec cover was added to alleviate skin irritation by wicking moisture away from the skin.

DISCUSSION

Sarah and her caregivers report guarded success with this latest headrest. They find that it is much more adjustable and easier to use than the original design. It allows Sarah to have better visual access to her surroundings and it improves other people's view of her. Her pressure sore is healing. Sarah still has difficulty using it for very long periods of time. When it is positioned as a cheek support rather than forehead, moisture can be a problem. Sarah did say that it worked really well to watch a production at a local theatre.

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ANALYSIS OF VIBRATION AND COMPARISON OF FOUR WHEELCHAIR CUSHIONS DURING MANUAL WHEELCHAIR PROPULSION

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ABSTRACT
The purpose of this study was to compare four cushions, a Jay Active (JA), a PinDot Comfort-Mate (PDCM), a Roho Low Profile (RLP), and a Varilite Solo (VS), based on their ability to minimize the vibrations transmitted from the wheelchair to the individual during manual wheelchair propulsion (MWP). Accelerometers measured the vibrations at the wheelchair/cushion interface and at the individual's head as the individual traversed an obstacle course. The VS performed the best, followed by the PDCM, the RLP and finally the JA, suggesting that a combination of foam and air minimizes the transmission of vibration. Cushions designed for static pressure relief may not perform well in other areas potentially related to secondary injuries such as vibration.

INTRODUCTION

Typically, cushions are prescribed by clinicians based on the cushion's pressure distribution properties, especially under the ischial tuberosities and the sacrum. Active individuals may need a firm cushion (e.g. foam based rather than air based) in order to perform independent transfers, or a light cushion in order to minimize the weight of the wheelchair/seating system.

The ability of the cushion to minimize impact (shock) and cyclic (repetitive) vibrations an individual experiences is typically not considered. Whole-body vibration experienced during manual wheelchair propulsion (MWP) can decrease an individual's comfort and increase the rate of fatigue [1]. Exposure to whole-body vibration has been shown to exceed the comfort and fatigue thresholds during MWP [2, 3]. This may adversely affect the physical performance of the individual. It may lead to social inactivity since the individual becomes fatigued faster. Finally, it may lead to poor body mechanics during MWP, transfers, or other activities of daily living, consequently increasing the individual's susceptibility to developing a secondary injury.

The purpose of this study was to compare four cushions, a Jay Active (JA), a PinDot Comfort-Mate (PDCM), a Roho Low Profile (RLP), and a Varilite Solo (VS), based on their ability to minimize vibration transmission from the wheelchair to the individual during MWP. Determining the cushion that minimizes vibrations provides clinicians additional information when recommending the most appropriate cushion. This is especially relevant in today's healthcare environment where letters of medical necessity are required by the majority of funding agencies.

METHODS

A triaxial accelerometer (Analog Devices ADXL05, ±4g) was mounted on a seat-plate which rested on the wheelchair's seat tubes (rails). The cushion was then affixed on top of the seat-plate. The accelerometer was positioned midway between the ischial tuberosities, directly below the sacrum. A second triaxial accelerometer was mounted on a bite-bar. The bite-bar was held between the individual's teeth, with a mouth guard to protect his/her teeth. This accelerometer measured the vibration experienced by the individual at his/her head. The acceleration signals were sampled at 200 Hz via a battery powered custom-designed data acquisition system [4].

A total of 10 unimpaired individuals propelled an instrumented wheelchair (Invacare XTR) while negotiating nine obstacles 48 times (four cushions by four back supports by three trials). Only the cushions were examined in this study, rather than the back supports or complete seating systems. The nine obstacles consisted of a unidirectional (a.k.a. rumble) strip, a ramp (1:25 slope), a curb drop (5 cm), a simulated door threshold, three sinusoidal bumps of varying height, a strip of truncated domes (a.k.a. dimple strip), and carpet.

The seat-plate and bite-bar accelerations were compared using the following equations:

$$RR = \frac{max(BB) - min(BB)}{max(SP) - min(SP)} \quad (1)$$

$$RMSR = \frac{RMS(BB)}{RMS(SP)} \quad (2)$$

where max(BB) and max(SP) are the maximum vertical accelerations recorded at the bite-bar and seat-plate, respectively, min(BB) and min(SP) are the minimum vertical accelerations recorded at the bite-bar and seat-plate, respectively, RR is the range ratio comparing the range of bite-bar vertical accelerations to the range of seat-plate vertical accelerations, and RMSR is the root-mean-squared (RMS) ratio comparing the RMS of the bite-bar vertical accelerations to the RMS of the seat-plate accelerations. The RR describes the cushion/human system's (CHS) ability to minimize peak vibrations, which are primarily due to impact vibrations (e.g. traversing the curb drop). The RMSR describes the CHS's ability to minimize the cyclic vibrations (e.g. traversing the unidirectional strip or repetitive motions of MWP). For both ratios, a value below one indicates the CHS reduces the vibrations, whereas, a value above one indicates the CHS amplifies the vibrations.

The cushions were compared for significant differences using a mixed-model ANOVA with a Bonferroni post-hoc test ($p<0.05$). The mean RR and RMSR values for each cushion were determined by averaging these values across the backs and trials. The RR and RMSR means were used as data points in the statistical analysis. The mixed-model ANOVA was performed using the statistical software package, SAS [5]. A mixed-model ANOVA was implemented in order to account for the fact that the data for each cushion was obtained from the same group of individuals. A single-factor ANOVA could not be implemented because the data violates the assumption that the groups of individuals were independent.

RESULTS

The mean plus/minus the standard deviation of RR and RMSR across ten participants are listed in Table I. The cushion with the lowest (i.e. best) ratios was the VS, followed by the PDCM, the RLP, and finally, the JA. The RR and RMSR of the VS were significantly different than the other three cushions ($p<0.05$). The RR of the PDCM was significantly different from the JA ($p<0.05$). The CHS reduced the range of peak accelerations (RR<1) and amplified the RMS accelerations (RMSR>1).

Table I. Mean ± Standard Deviation (n=10) of the Range Ratio (RR) and the RMS Ratio (RMSR) for the four cushions. The letters A, B, C, or D indicate a significant difference at the p<0.05 level.

Cushion	Range Ratio (RR)	RMS Ratio (RMSR)
A. Varilite Solo (VS)	0.41±0.088: B, C, D	1.32±0.16: B, C, D
B. PinDot Comfort-Mate (PDCM)	0.48±0.095: A, D	1.39±0.16: A
C. Roho Low Profile (RLP)	0.48±0.094: A	1.41±0.19: A
D. Jay Active (JA)	0.52±0.10: A, B	1.43±0.18: A

DISCUSSION

The RR and RMSR for the VS is significantly less than the other three cushions used in this study (Table I). The VS is composed of a foam base below an adjustable air pocket. This combination minimized the transmission of impact vibrations (i.e. due to shock), as described by the RR, and cyclic vibrations (i.e. due to repetitive motions), as described by the RMSR. The PDCM (foam only) and RLP (air only), had similar results, but were in contrast to the results of the VS (foam and air), suggesting that that vibrations are minimized by the interaction of the air and foam, rather than one or the other.

The results obtained by the JA cushion, which generated the largest (i.e. worst) RMSR and RR values, can be explained by the material properties of the cushion. This cushion consists of a contoured foam base below a gel layer. Gel has inadequate reactive properties, that is, it feels like a solid object when the individual encounters impact vibrations. This is because it is designed to provide pressure relief in static or pseudo-static situations, rather than to absorb vibrations. Since the gel is extremely stiff during impact and cyclic vibrations, the foam base is the only component which has the ability to minimize the vibrations transferred to the individual, likely producing poor results relative to the other cushions.

Currently, the main focus of cushion design is on appropriate pressure distribution, especially under the ischial tuberosities and the sacrum. The JA and RLP are typically used by clinicians for individuals who are at a greater risk of developing pressure sores. However, the RLP and JA may not be the ideal cushions for active users, especially in minimizing vibration. As described in the introduction the amount of vibration an individual experiences will directly affect the individual's comfort and rate of fatigue. This could compromise the individual's ability to actively participate in the community and independently perform activities of daily living.

The RMSR and RR are accurate metrics to determine a cushions ability to minimize the vibration transmitted to the individual. Both parameters were consistent in rating the cushions, and in discriminating that the VS was significantly better than the other three cushions (Table I). The RR indicated that all the CHSs were able to reduce the range of vibrations experienced by the individual (RR<1). Upon initial examination of the RMSR it appeared that the CHS increased vibration transmission (RMSR>1). This is due to the fact that the vibrations experienced during MWP were in the same frequency range as the natural frequencies of the human body [6]. Therefore it is appropriate to suggest that the RMSR parameter was greater than one due to the properties of the human body rather than the cushion. Since the individuals remained constant across groups, any differences in the RMSR were a direct result of the different cushions used in this study.

Future investigations will examine the RMSR and RR parameters on an obstacle by obstacle basis, will compare back supports and seating systems rather than just cushions, will examine parameters in the frequency domain rather than the time domain, and will include individuals who use a manual wheelchair as their primary form of mobility.

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COMPARISON OF THE TRUNK LATERAL STABILITY PROVIDED BY FOUR TYPES OF WHEELCHAIR BACKRESTS

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ABSTRACT

The flexible contour backrest was designed to offer a postural stability similar to the one provided by back cushions on rigid surfaces while keeping sling back upholstery's advantages. This study compare the lateral trunk stability provided by this wheelchair backrest and three others (one sling backrest and two back cushions on rigid interface) for 15 spinal cord-injured subjects. A platform that can be laterally tilted was used to create instability of the subject seated in a wheelchair. During tilting, spherical reflective markers fixed on the subject and the wheelchair structure were tracked using a Motion Analysis system. Results showed that subjects seated with the flexible contour backrest reached a maximum platform tilt angle value (14.1 ± 3.5°) that was significantly higher than the one obtained with the sling backrest (8.0 ± 4.2°) and similar to the back cushions on rigid surfaces one.

INTRODUCTION

The simplest form of trunk support for wheelchair users consists of a conventional sling backrest. The imposed configuration of the wheelchair sling backrest, biomechanically necessitates that a person with limited trunk control assumes an abnormal sitting posture (Hobson & Tooms, 1992; Harms, 1990; Minkel, 1989; Zacharkow, 1984). As the sling backrest does not provide proper body stabilization, the wheelchair user must stabilize himself. This will require an additional expenditure of energy due to increased muscular effort. This energy will be no more available to fonction in activities across all the performance areas. Today, there is a wide variety of wheelchair backrests which were designed to increase lateral trunk stability (Stone, 1996; Trefler et al., 1993). The most popular are back cushions on rigid surfaces. Unfortunately, they deprive many wheelchair users of the advantages of the sling backrests (foldable, light, discrete and low cost; Parent, 1997; Zollars, 1993; Valiquette, 1992; Harms, 1990; Zacharkow, 1984). As a compromised solution, the concept of a contoured sling backrest, that can offer lumbar and lateral trunk support, was introduced by Valiquette & Audet (1992). This concept was redesigned and presented under the name "flexible contour backrest (FCB)" (Parent et al., 1997). The main purpose of the actual study is to compare the effect of two back cushions on rigid surface (Jay Back by Jay Medical Ltd. and Apex backrest by Orthofab Inc.), a sling backrest with adjustable straps (Orthofab Inc.) and the flexible contour backrest (Orthofab Inc.) on lateral trunk stability for fifteen spinal cord injured people.

METHOD

Fifteen spinal cord-injured subjects (injury level varying from C_5 to C_7) using manual wheelchair participated in this study: 13 males and 2 females. Most of the subjects (63%) were between 30 and 40 years of age. Out of them, 94% were using a sling backrest (47% with adjustable straps). During the evaluations, subjects followed a specific positioning procedure in a Concerto manual wheelchair (provided by Orthofab Inc.). The seat tilt angle was fixed at 7.5°. The seat-to-back angle was determined by an occupational therapist in order to conform as well as possible to the subject's trunk geometry and stability. Each backrest component was adjusted by the same occupational therapist. Backrest height was fixed at 40 cm above the seat surface. The subjects were using their own cushion during the evaluation. An anchorage system was used to fix the wheelchair on a platform that can be laterally tilted up to 17° using a lifting jack (Fig. 1). Spherical reflective markers were fixed on the subject and the wheelchair structure (Fig. 1): right and left acromions processes (markers 1 and 2) and right and left side of the wheelchair (markers 3 and 4). For each backrest, the platform was manually tilted at a speed of 0.3 degree/sec, while a research assistant took care of the subject. When the subject was starting to loose balance, the platform was lowered at a speed of approximately 1 degree/sec. During the tilting of the platform, the markers were tracked using a Motion Analysis system (Expert Vision System from Motion Analysis Corporation, Santa Rosa, CA) and their trajectories were obtained from the ExpertVision software. From these data, two geometrical indices were calculated (Fig. 1): maximum wheelchair frontal tilt (WFT) reached by the subject and trunk lateral tilt (TLT) when WFT = 9°. All the 15 subjects had reached this platform tilt angle for the flexible contour backrest and the two back cushions on rigid surfaces. Value of the TLT index for the sling backrest was not calculated since only 5 subjects have reached this platform tilt angle.

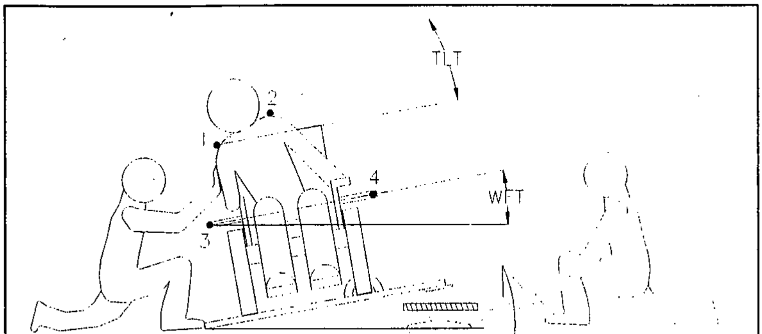

Figure 1: Schematic representation of the tilt platform designed to evaluate lateral stability provided by the backrests and stability indices calculated from trunk and wheelchair markers.

RESULTS

Table 1 presents a summary of the lateral stability indices for all backrests. While seated with the sling backrest, the subjects reached a significantly lower maximum platform tilt angle value (8.0° ± 4.2°) than the ones obtained with the other backrests. On the opposite, subjects seated with the Jay Back reached a significantly higher maximum platform tilt angle value (16.0° ± 1.6°) than the one obtained with the other backrests. No significant difference was found between the flexible contour backrest and the Apex backrest. For the TLT index, no significant difference was also found between the flexible contour backrest and the two back cushions on rigid surfaces, where standard deviations are very high with respect to the means.

Table1: Summary of the stability indices for the 15 evaluated subjects for the four backrests.

Parameters	Sling backrest	Apex backrest	FCB	Jay Back
Maximum value of WFT	8.0° ± 4.2°	12.4° ± 3.6°	14.1° ± 3.5°	16.0° ± 1.6°
TLT when WFT = 9°	---	5.4° ± 7.6°	2.6° ± 7.9°	4.4° ± 10.2°

DISCUSSION

One of the flexible contour backrest design objectives was to offer lateral trunk stability as back cushions on rigid surfaces can do. Results of maximum value of WLT showed that the flexible contour backrest provides similar lateral trunk support effect than the two back cushions on rigid surfaces (Apex backrest et Jay Back). However, the number of subjects who have reached the maximum platform angle (17°) is higher with the Jay Back than the flexible contour backrest. This may be explained by the fact that the lateral supports are deeper on the Jay Back (6 inches) than on the flexible contour backrest (4 inches). Nevertheless, many subjects complained against the depth of the Jay lateral supports. They have indeed expressed their discomfort and fear of being less functional in transferring or reaching tasks. On the other side, the sling backrest did not provide sufficient lateral support as most of the subjects loose their balance very quickly. For the TLT index, it is difficult to analyze the results since the variations between subjects are very high. This may be explained by the fact that some subjects has a tendency to compensate during the tilting of the platform while others let their trunk fall on the side.

CONCLUSION

The method used in this study allowed to discriminate between four wheelchair backrests in term of lateral trunk stability. It was shown that subjects seated with the flexible contour backrest had better lateral trunk stability than when seated with the sling backrest. This relatively new concept, if well used, could represent a compromise between back cushions on rigid surfaces and sling backrests to fulfill the needs of many wheelchair users in term of postural control.

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POSTURAL ADJUSTMENT DURING REACHING IN PARAPLEGIC SUBJECTS.

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ABSTRACT

The purpose of this study is to examine the effect of seat cushions on postural ajustment in sitting during a controlled voluntary perturbation for nine wheelchair users with paraplegia. Three types of cushions, air flotation (Roho), a generic contoured (Iscus) and Flat (FF) polyurethane foam, were tested during a controlled reaching task in ispilateral and contralateral direction, at 45° from the sagittal plane. During the reach, center of pressure (COP) coordinates were measured using a pressure measurement system as well as a force platform under seat. The contoured cushion (Iscus) allows the COP to cover a large distance at higher speed when compared to the Roho or FF cushion. Maximal pressure under ischial tuberosity can reach higher value of 275 mmHg and 235 mmHg for FF and Iscus cushions respectively, whereas it stays lower for the Roho cushion (143 mmHg). In conclusion, seat cushions can significantly affect sitting balance during reaching tasks, and the trade-off between dynamic stability and peak pressure has to be made in practice. This study provides an objective way to realize this trade-off, and has an implications for wheelchair seating recommendations and especially for seat cushion selection.

BACKGROUND

Sitting is a common and familiar position used daily as platform for motor activities; it develops before standing, and it is present in subjects with certain physical impairments who cannot stand. Dynamic sitting refers to the continuous process of postural changes during sitting. The sitting posture is basically unstable, and research indicate that the threshold for postural adjustments are higher during sitting than during standing, and higher for forward sway perturbation than for backward sway perturbation [1]. Research related to the quantification of sitting stability has been oriented towards applications such as postural sway measurements and functional reach, as well as wheelchair stability. It is well known that the stability provided by the seat cushion is considered to be the most important characteristic of sitting support after the pressure distribution. The effect that the cushion has on stability, although real or perceived, can be critical especially for users with poor trunk control. Persons with spinal lesions often have an acute awareness of their trunk stability that is far more subtle and complex than position measurement systems are able to detect [2]. In functional reach however, the manner in which the body is stabilized while performing reaching tasks is not well understood. Seelen et al. [3] had shown a clear improvement in controlling sitting posture by an increase of center of pressure (COP) displacement in high and low spinal cord injured (SCI) groups, after a period of rehabilitation program. However, the effect of seat cushion on sitting balance has not been examined from a quantitative viewpoint in the previous studies. In fact, in most of the studies, except one [4] a hard seat was used, or the subject even sat directly on a rigid force-platform. This lack is merely due to the fact that it is difficult to estimate COP at the body-seat interface. Kamper et al [4] studied the effect of seat surface on postural control during lateral perturbation in a group of able-bodied and paraplegics. However, the authors [4] did not found significant differences between flat-foam and Roho cushions on the center of gravity displacement. In a recent study, Aissaoui et al [5] developed a method to assess the dynamic stability of seat cushion based on COP information as estimated from pressure measurement system. The group of population that participate in the study [5] was ambulatory.

RESEARCH QUESTION

The objective of this study is twofold: (i) to assess the effect of seat cushion on dynamic stability during reaching tasks on paraplegic subjects; (ii) and to compare the pattern of the stability indexes as obtained from pressure measurement system and force-platform system

METHOD

Nine paraplegic subjects participate in this study. To participate, subjects had to meet the following criteria : (i) diagnosis of paraplegia resulting in complete or incomplete spinal lesion for at least 12 months; (ii) no pressure sore for at least one year; (iii) the range of spinal lesion level was limited to T7-L2; (iv) be able to sit for a period of one and half hour. All procedures were performed in accordance with the approval of the Rehabilitation Institute of Montreal's Ethic's Committee. The experimental protocol has been fully described in [5], and it is summarized here. The subjects were asked to reach a target located at 130% of their arm length in ipsi and contra-lateral directions at 45° from the sagittal plane. During the reach, COP was estimated form both an AMTI force-platform and FSA (Force sensing array) systems. Maximal displacement (MCD) and maximal velocity MV of COP as well as surface area (SF) under the phase diagram of the COP were measured for three type of cushions (Roho 3", a 2" polyurethane HR35 flat-foam FF, and 3" polyurethane HR45 contoured foam Iscus). Each dependent variable (MCD, MV, and SF) was analyzed separately in an ANOVA (2 factors) with repeated measures on both independent variables (cushion and direction), to determine if significant differences existed among the 3 cushions. If indicated, a Bonferroni test was performed to determine which pairs of means were significantly different ($p<0.05$).

RESULTS

All subjects were able to perform reaching tasks at 130% of their arm length except for one subject who was only able to reach at 115%. During the forward motion of the reaching task with the right hand, the MCD parameter was larger for the Iscus cushion (81 mm) when compared to the Roho (63 mm) and FF (61 mm) cushions. The analysis of variance reveals that there was a cushion effect ($F=3.99$; $df=2,16$; $p<0.05$) and a direction effect ($F=18.65$; $df=1,8$; $p<0.01$) when reaching with the right hand. The Iscus cushion has a significant effect ($p<0.05$) on MCD parameter comparatively to the flat-foam and the Roho cushions. The average maximal velocity of the COP was significantly higher ($p< 0.01$) for the Iscus (0.14m/s) than for the Roho or the FF cushions (0.10 m/s). In summary, for all of the MCD, MV and SF parameters the Iscus cushion was significantly different from both the Roho and the flat foam cushions. However, the foam cushions (Iscus and FF) exhibit more asymmetry than the Roho. Maximal pressure under right ischial tuberosity was significantly higher for FF cushion (275 mmHg) and the Iscus (235 mmHg) compared to the Roho (143 mmHg). Results from seat force platform exhibit the same pattern than the pressure measurement system used in this study (FSA system).

DISCUSSION

The purpose of this study was to investigate the effect of seat cushion on dynamic stability during a controlled reaching task. The major finding of this study was that paraplegic subjects were able to increase both the distance covered, and the velocity of the COP when the contoured cushion (Iscus) was used during reaching. This result was confirmed by data gathered from both the seat force platform (AMTI) and the pressure measurement system (FSA). The MCD value found in this study compared well with the data of Kamper et al.[6], who found that maximal lateral displacement of the

COP for paraplegic subjects was about 73.2 mm. This displacement represented however, the limit of the COP movement that the subject could maintain without the use of the upper extremities when leaning to the right side. It should be noted here, that seat cushion in the earlier study [6] was made by two layers flat-foam (5 cm of HR70 topped by 2.5 cm of HR32). The MV parameter found in this study as estimated from the seat platform (MV =0.18 m/s) is similar to the mean value obtained by Seelen [7] (MV=0.17 m/s) for his low thoracic paraplegic group. The ability for the COP to cover a large distance with high velocity appears to be linked to the increase in stability during reaching. The center of pressure is generally viewed as the neuromuscular response to imbalances of the body's center of gravity. This means that during reaching task, the COP is continuously tracking the body's center of gravity, and therefore the horizontal distance between the center of gravity and the COP should always be minimized to assure stability. In this sense, a seating device that allows the COP to cover fairly a large distance with higher velocity should be considered as stable. This characteristic of the cushion should then improve wheelchair user's stability during activities of daily living. In this study, higher pressure were recorded when the foam cushions (Iscus and FF) were used. However, these peak pressure correspond to the instant at mid-distance of reaching target, and do not represent static pressure data. In a similar dynamic movement, Kernozek & Lewin [8] found that peak pressure under the ischial tuberosity region increased by 42% during manual wheelchair propulsion to reach a value of 272 mmHg/sec in individuals with paraplegia, when they sat on Jay Active cushion. This study provides some insights into dynamic stability of wheelchair users. Finally, The method presented here, objectively discriminate between cushions in term of their stability characteristics.

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Time Dependent Response of Wheelchair Seating

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ABSTRACT

During the wheelchair prescription process it is common to utilize a pressure measurement mat to select a seat cushion selection and aid in determination of the optimum tilt and recline angles. This study investigated the time dependent response of the pressure measuring mat as well as the wheelchair user and cushion. From the experimental results, the importance of obtaining the pressure response at a consistent time interval after the load is applied, is demonstrated for both clinical and research studies.

BACKGROUND

Pressure-mapping systems are employed by clinicians, researchers, and designers to evaluate interface pressures. Interface pressures are used to assess for cushion prescription, performance, design and development. Efforts have been made to standardize interface pressure testing in order to collect objective, repeatable data. The elasticity of tissues and materials used in cushions (1), (2) is recognized as having an impact on interface pressure measurements.

In a past study on body/seat interface pressure distribution during wheelchair seating (3), it was found that interface pressure did not decrease as a function of tilt angle from 0 to 45. This result was unexpected. For that study, test subjects were placed in the wheelchair and measurements were made from the minimum value of tilt through the maximum value with the test subject on the seating system the entire time (approximately ½ hour). However, the time dependent behavior of the seat cushion, pressure sensor mat, and subject tissue were not taken into account.

RESEARCH QUESTION

The objective of this study was to determine the time dependent response of pressure measurement during wheelchair seating. Once the time dependent response of the pressure measurement system is determined the actual time dependent response of the user and cushion can be evaluated. This will allow more accurate interpretation of interface pressure measurement and the response to tilt angle.

METHOD

The time dependent response of a commercially available pressure measurement mat (Ultrathin FSA) was determined by placing the mat on a steel surface and then loading the mat with steel weights. The response of individual measurement cells was monitored as a function of time. Due to the variation of their response, cells below 10 mm of Hg were not used to determine the response of the measurement mats. A range of other cells from 20 to 150 mm Hg were normalized and averaged to determine the response of the sensor and mat as a function of time.

The Ultrathin FSA mat was subsequently used to determine the responses of a foam test cushion (Jay Combi) and a single test subject. The cushion response was determined by placing the mat on a cushion in a wheelchair and loading with 27 kg of steel weights. Next the able-bodied test subject was utilized instead of the steel weights, as in the typical clinical use of the pressure mat. Both of these tests were run for 30 minutes.

In order to investigate more thoroughly the results of previous research (1) and account for the effect of continually sitting in the wheelchair during tilt testing, additional tests were run tilting the wheelchair from 0 to 45°, while the angle between the seat and back was held constant at 90°. A comparison was made between tests where the subject sat in the wheelchair during the entire test as in the previous study and a series of tests where the subject exited the wheelchair between measurements and tilt positions. For the continuous sitting test the subject sat in the chair and the tilt angle was varied in 5° increments. The pressure readings were obtained every 4 minutes. Immediately after a pressure reading at a given tilt angle, the tilt angle was changed to the next value. Thus the duration of this testing was 36 minutes. For the discrete sitting test, the subject sat in the chair at 0°tilt and the chair was then tilted to the desired tilt angle. The subject was seated for 4 minutes prior to the pressure measurement being taken for this non-continuous testing. Once the pressure reading was taken the chair was returned to 0° tilt and the subject exited the chair in preparation for another cycle.

RESULTS

The first step in gaining an understanding of the time dependent response is to evaluate the response of the pressure measurement mat. The response of the mat is shown in Fig. 1. The pressure readings were normalized by the maximum pressure reading in order to compare between various cells. Note also that the scale on normalized pressure is shown from 0.75 to 1. The expanded scale elucidates the changes with respect to time, but does not demonstrate that the curves (as exhibited without the expanded scale) are indeed flattening out in the time frame shown.

Figure 2 shows the response for the pressure measurements directly under the ischial tuberosities of a test subject. There was a definite asymmetry to the load distribution. As can be seen from this figure, the changes in pressure readings from the combined effect of cushion and subject are much greater than the changes from the pressure mat alone. The FSA Ultrathin pressure mat alone exhibits an approximately 15% change over 2000 s while the combined system change is approximately 100% over the same period of time. By normalizing the data of Fig. 2 it can be shown that the response under both ischial tuberosities is following the same trend. However, it should be clear from Fig. 2 that the pressure has not approached an asymptotic value.

Comparison of the results of continuous sitting tilt testing and the non-continuous sitting testing demonstrate that the pressure readings for continuous sitting are greater than the readings when the subject has only been seated for 4 minutes. In addition, this testing exhibited a reduction of both average and maximum pressure as the tilt angle was increased.

DISCUSSION

The results demonstrate that there is a definite time dependence to the response of the components that make up the seat/user interface. Reasons for this are many. The pressure sensors are not purely elastic, and even if they were, they are typically embedded in a viscoelastic polymer medium. Certainly the cushion foam and tissue of the buttocks are viscoelastic in nature. Thus, the simplest model that can be conceptualized for the seating system including the user is of three time dependent elements in series. This corresponds to a column of viscoelastic tissue on a time dependent sensor that is on a viscoelastic foam. Beyond that the tissue covering the ischial tuberosities is potentially behaving as a non-linear spring that stiffens with increased deflection and thus time. The time dependent nature of the response of this system leads to the conclusion that both the clinician and researcher should make pressure measurements at a fixed time after placement of the test subject in the wheelchair. Even when this is done the results are only relative. In order to determine absolute pressures, it is necessary to calibrate the pressure mat at a known time from application of the pressure and determine the response of the mat as a function of time in order to estimate the true absolute pressure.

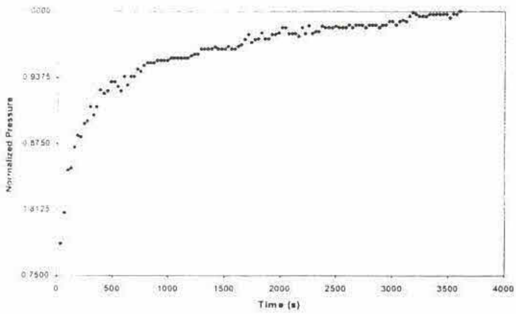

Figure 1. Time Dependent Response of Pressure Measurement Mat

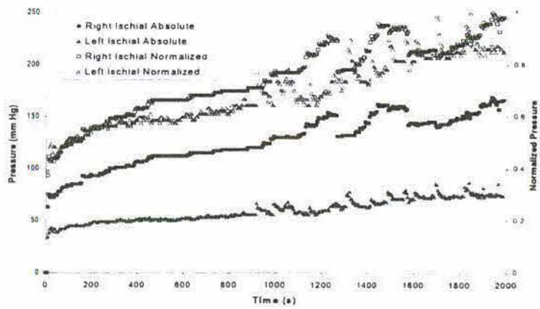

Figure 2. Response of Subject, Cushion, and FSA Ultrathin Mat

Comparing the continuous sitting tests to the non-continuous sitting tests demonstrates the behavior that would be expected from observations of the time dependent nature of the subject/sensor/cushion system. For continuous sitting, the readings are higher than they are for non-continuous sitting. Subsequent testing reveals that maximum and average pressures are decreasing with increasing tilt angle.

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CLIMATIC TESTING OF FIVE DIFFERENT TYPES OF POWER WHEELCHAIRS

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ABSTRACT

This study was intended to determine the ability of five different power wheelchairs to withstand extreme environmental conditions. Fifteen power wheelchairs were tested according to Section 9 of the ANSI/RESNA Wheelchair Standards. The Pride Healthcare Jazzy equipped with a Penny & Giles controller failed the rain condition test. The Sunrise Medical Quickie P200 equipped with a Penny & Giles controller and the Everest & Jennings Lancer 2000 equipped with a Penny & Giles controller failed the cold operating condition test. Overall, one third of the wheelchairs tested failed at least one section of the standard.

BACKGROUND

The technology to design and produce power wheelchairs is advancing every year. Controllers are often required to perform numerous tasks, and people use their power wheelchairs in all types of environmental conditions. It is imperative that the wheelchair and its electronics be able to withstand extreme conditions. Section 9 of the ANSI/RESNA Standards is a test for the ability of a power wheelchair to withstand extreme climatic conditions. It is intended to insure that a person caught in the rain or traveling outside in the winter will not be stranded due to a malfunction with their wheelchair. Unfortunately, very few laboratories have the necessary equipment to perform climatic testing. Therefore, data on this subject is not readily available to consumers. Most information that is available is outdated (1). The purpose of this study was to determine whether different types of popular power wheelchairs could hold up under severe conditions.

The fifteen power wheelchairs selected for this study were purchased through three different dealers. The manufacturers did not know that these wheelchairs were going to be tested and therefore no special steps were taken to guarantee that they would pass the tests.

RESEARCH QUESTION

Is there a difference in the performance of five different types of power wheelchairs when tested according to Section 9 of the ANSI/RESNA Standards- Climatic Tests for Electric Wheelchairs?

METHOD

Five different types of power wheelchairs were selected for this study. Three wheelchairs of each type were purchased for testing. These wheelchairs include; the Invacare Action Storm (Invacare MKIV controller), the Sunrise Medical Quickie P200 (Penny & Giles controller), the Everest & Jennings Lancer 2000 (Penny & Giles controller), the Permobil Chairman (Penny & Giles controller), and the Pride Healthcare Jazzy (Penny & Giles controller).

The fifteen wheelchairs included in this study were all tested according to Section 9 (Climatic Tests for Electric Wheelchairs) of the ANSI/RESNA Wheelchair Standards (1). Section 9 is subdivided into five main tests.

Subsection 7.3 (Rain Conditions) entails applying water spray to the wheelchair. A functionality check is then performed within five minutes of completion of this test. The wheelchair is then allowed to sit for one hour at 20± 5°C. Another functionality check is then performed to determine whether any damage has occurred to the wheelchair. The functionality test involves driving the wheelchair in a forward direction in a loop around a marker. The wheelchair is then driven in the reverse direction around the same track. The wheelchair fails the test if the driver observes any abnormal responses.

The methods for performing Subsections 7.4, 7.5, 7.6, and 7.7 are all summarized in table 1.

Section	Condition	Temperature	Time	Functionality Test
7.4	Cold Operating	-25°C +2/-5°C	≥ 3hrs	< 5 min. after test
7.5	Hot Operating	50°C +5/-2°C	≥ 3hrs	< 5 min. after test
7.6	Cold Storage	-40±5°C	≥ 5hrs	1 hr after test
7.7	Hot Storage	65±5°C	≥ 5hrs	1 hr after test

Table 1

All testing was performed in a Tenney Environmental Chamber. The chamber has a temperature range of 200°C to –40°C and the humidity can be adjusted from 0 to 99%.

RESULTS

The results of climatic testing are presented in table 2.

Wheelchair	Sec. 7.3	Sec. 7.4	Sec. 7.5	Sec. 7.6	Sec. 7.7
#1 Action Storm	Pass	Pass	Pass	Pass	Pass
#2 Action Storm	Pass	Pass	Pass	Pass	Pass
#3 Action Storm	Pass	Pass	Pass	Pass	Pass
#4 Quickie P200	Pass	Pass	Pass	Pass	Pass
#5 Quickie P200	Pass	Pass	Pass	Pass	Pass
#6 Quickie P200	**Fail**	Pass	Pass	Pass	Pass
#7 E&J Lancer	Pass	Pass	Pass	Pass	Pass
#8 E&J Lancer	**Fail**	Pass	Pass	Pass	Pass
#9 E&J lancer	**Fail**	Pass	Pass	Pass	Pass
#10 Permobil	Pass	Pass	Pass	Pass	Pass
#11 Permobil	Pass	Pass	Pass	Pass	Pass
#12 Permobil	Pass	Pass	Pass	Pass	Pass
#13 Pride Jazzy	Pass	**Fail**	Pass	Pass	Pass
#14 Pride Jazzy	Pass	Pass	Pass	Pass	Pass
#15 Pride Jazzy	Pass	**Fail**	Pass	Pass	Pass

Table 2

A total of five of the fifteen wheelchairs tested for this study failed at least one part of the standards. Two of the Everest & Jennings Lancer 2000 wheelchairs and one Quickie P200 failed the rain test. E&J #8 appeared to function normally at first, however, after driving backwards and hitting the anti-tip bars, power was lost and could not be restored. One hour later the wheelchair functioned normally. E&J #9 also appeared to function normally, however, after traversing a curb, the wheelchair would not drive. One hour later the wheelchair was able to drive again, however, it would also drift backwards while the joystick was in the neutral position. Quickie #6 drove backwards approximately 100mm while it was being sprayed with water. The controller also started to beep. One hour after the test, the wheelchair did not respond to movement of the joystick and the power could not be turned off.

Two of the Pride Jazzy wheelchairs failed the cold operating test. The controller on Jazzy #13 could not be turned on until five minutes after the test. Jazzy #15 could not be turned on until ten minutes after the test.

DISCUSSION

The results of the rain test demonstrate that it is vital for a wheelchair controller to be environmentally sealed. Two out of the three E&J wheelchairs tested failed the rain test. All of the wheelchairs that failed the rain test were outfitted with Penny & Giles controllers.

The cold operating condition test is another very important test. If a wheelchair malfunctions due to extreme cold, the user could die due to exposure if he/she becomes stranded. Two out of the three Pride Jazzy wheelchairs failed this test.

Overall, one third of the power wheelchairs tested for this study failed at least one section of the climatic test standard. All of the wheelchairs passed the hot operating and hot and cold storage condition tests. The cold operating test is perhaps the most significant test in this standard. Failure of a wheelchair to operate under this condition can present immediate danger to the user. The rain test is another very relevant standard. If a power wheelchair fails to function after getting wet, then the user could be severely inconvenienced after going through a puddle or getting caught in a rainstorm.

People who depend on power wheelchairs for mobility need to know that their wheelchair will function properly in all situations. Power wheelchairs are now being designed to take the user wherever they want to go under any condition. Controller and wheelchair manufacturers must make sure that their products will perform to the required standards in any circumstance.

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TALK, ACTION, ARTIFACTS TO SUPPORT VIDEOCONFERENCING

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ABSTRACT

Videoconferencing is an emerging technology opening new ways to provide mobility and seating customisation to individuals isolated from service providers. Effective use of video-conferencing by a city-based rehabilitation engineering (RE) team linking with a client in a country town requires understanding of how communicating in face-to-face service delivery functions. This understanding is being applied to develop techniques to acquire sufficient client information and measurement data to custom design and manufacture seating for individuals.

BACKGROUND

In health care videoconferencing technology is being grasped as a medium to overcome the tyranny of distance separating patients from medical specialist expertise. Queensland Health has made major investment in videoconference infrastructure to improve health care delivery in a State-wide public health system. Videoconference facilities exist in 144 Queensland State Hospitals and Community Health Centres communicating on ISDN lines. The scarcity of rehabilitation engineering services, particularly outside major population centres means innovative methods need to be devised and enacted to deliver rehabilitation engineering expertise to rural areas. Clients within population centres who are unable to travel to a service provider suffer a similar tyranny of isolation and would also gain benefit from receiving services based on videoconference communication. A city based rehabilitation engineering team have been videoconferencing with therapists and their clients living a long distance away to: (1) evaluate a client's function and propose ideas to the local therapist about assistive devices, (2) gain appreciation of a client's needs and equipment difficulties prior to a team visit, (3) measurement and data gathering for remote designing and fabrication of customised seating, (4) follow-up of the client after work has been done, and (5) education of local people dealing with the client.

STATEMENT OF PROBLEM

A small number of investigators have been developing suitable technology to connect people with a disability in remote areas to rehabilitation engineering services [1], [2]. Work must continue into making rehabilitation engineering video-consultation a practical tool. Rehabilitation engineering videoconferencing relies on sharing visual data and physical artifacts around which collaborative is based. This makes it different to current tele-medicine where there is no need to share actual physical components. Rather the sharing involves medical records, reports, X-ray and ultrasound images to support "talking heads" video-mediated communication.

Rehabilitation engineering practiced in a face-to-face Seating Clinic has four features that impact on the functioning of a remote link between client and rehabilitation engineering team: 1) rehabilitation engineering is a hands-on activity requiring physical investigation of the client, their equipment, and manipulated artifacts with a bearing on the problems to be solved, 2) engineered solutions require acquisition of data about positions, orientations, movements, shapes that is difficult to capture and record accurately without using sophisticated equipment, 3) if an interdisciplinary team is present its members interact with the client and care-givers and with each other according to turn-taking procedures that rely on visual and aural cues, 4) the Seating Clinic makes progress by both programmed and serendipitous activity. Each of these features is more difficult to fulfill using video-mediated communication.

RATIONALE

The mechanism for design information communication in a cross-discipline rehabilitation engineering team was investigated by Logan [3]. Data drawn form this extensive empirical study showed team members combined actions involving hands and artifacts with talk in 59% of communication events. In 78% of these events the action performed in synchrony with talk either gave meaning to what was said or identified the focus of the talk. These outcomes indicate extensive use of action with talk by the (face-to-face) team to enhance their communication and the need for participants to see actions in order to gain the full value of another person's talk. Logan and Radcliffe [4] considered that (i) the participants incorporated artifacts into their conversations, acted on the artifacts as part of the idea generation process, and applied this action to aid communication of ideas, and (ii) participants also placed great reliance on the capacity of their actions, particularly supported by artifacts to make their talk lucid. These aspects of rehabilitation engineering practice, i.e. high reliance on visual data and talk, require particular attention in video-mediated communication where the "co-present environment" [5] is absent.

DESIGN DEVELOPMENT

Our goal is to develop a network of therapists who feel comfortable and confident about using videoconferencing for rehabilitation engineering consultations. Initial videoconferences indicated the remote site participants did not know what to expect, what to do and time was consumed explaining what to do. Set-up issues like lighting colour of clothing, camera position unable to capture the action of interest, and difficulties with seemingly simple tasks like measuring prompted a rethink of how to videoconference. Some key principles have been beneficial to the conduct of videoconferences:

1. Develop an explanatory document outlining what is to happen and why, the limits of the process (what is hoped to be achieved), the role of the remote group, and instructions outlining the rules of conduct for videoconferencing. Documentation for consenting to image storage is advisable.
2. Assemble a toolkit of equipment complete with instructions on how to unpack, use, repack that can be shipped to the remote videoconference site for use by the therapist and client group. Our toolkit contains measuring equipment, a video on how we want measurements taken, a variety of seating artifacts for the remote group to use either serrendipitously or under instruction from the RE team. A digital video camera is provided to (a) take video of the client in the home, school, community environments that will influence design ideas and (b) link into the remote site videoconference system to provide a high quality picture for seeing detail at the RE site.
3. Run a test videoconference with the remote site therapist (at least the first time) without the client to establish rapport and basic understanding of how the client session will run and to check that basic issues like taking measurements and shapes of the client have been understood.
4. Seek feedback from the remote site immediately at the conclusion of the videoconference to get an appreciation for what they felt happy with, uncomfortable with etc. to incorporate next time.

To date, two customised seating systems have been fabricated from measurements made by the remote therapist during the videoconference and the client's back profile flexicurve tracings returned by facsimile. A major difficulty is no trial occurs prior to upholstering to test for problems in real use. Shipping the wheelchair to the client and reviewing by videoconference before shipping it back for upholstering is possible, but increases costs. The limit to how complex a seating system can be fabricated in isolation from the client rests with the quality of artifacts that are available at the remote site to convey data about size, shape, orientation. Consideration is being given to the type of artifacts, possibly in the form of a versatile assessment wheelchair that could enhance remote design data collection. Futuristically, one could envisage haptic sensors in a virtual reality seating system providing sensation to the wheelchair user about support and comfort and providing performance data to the RE team to aid design.

DISCUSSION

Good outcomes occur when client - RE interaction proffers talk and action communication, draws out user experiential information, and induces idea generation. Re-creating the common reference in video-mediated communication for RE requires:

- Remote and local site participants must have decided the purpose of the videoconference and the expectation of the interaction.
- Establish a protocol with the remote site to replace the turn-taking mechanisms that are not available to control the flow of interaction. Serendipity will decrease but effective use of time and acquisition of specific information will occur.
- Actions that a participant might use in association with their talking must be visible to all participants,
- Artifacts must be available for participants to use in order to aid development of ideas and testing of concepts through simple prototyping.
- Visual detail must clearly show measurements, relative positioning of components, motion, etc,

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AN EVALUATION OF AN OBSTACLE AVOIDANCE FORCE FEEDBACK JOYSTICK

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ABSTRACT

An evaluation of a variable compliance force feedback joystick for a power wheelchair was performed. The study aim was to determine if the device enhanced the driving performance of experienced wheelchair users. A prototype device was constructed and used with a virtual reality system for evaluation. The factors that were used to adjust the compliance of the joystick were 1) the angle between the wheelchair velocity vector and the edge of the closest obstacle and 2) the speed of the wheelchair. The results showed that four out of the five subjects who participated in the study had fewer collisions when the force feedback algorithm was activated compared to their performance when the algorithm was not activated.

BACKGROUND

Many varieties of power wheelchair input devices and control interfaces have been developed to satisfy the diverse needs of people with disabilities. However, there are still some people with physical impairments for whom there are currently no input devices that provide independent mobility (1). Previous studies have investigated the use of wheelchairs that are able to detect obstacles and provide obstacle-avoidance features (2,3). In these systems, the wheelchair automatically avoids detected obstacles, temporarily limiting the driver's ability to control the wheelchair. In order to capitalize on the benefits of obstacle detection while providing the driver with consistent control, this study introduces a force feedback joystick. With the force feedback joystick, the wheelchair senses obstacles, warns the user, and prompts the user with a course of action; but the driver remains in control and can override the wheelchair's suggested path.

Two algorithm philosophies have been considered. In the first algorithm, passive assist, the joystick would simply resist movement in the direction of a sensed obstacle. In the second algorithm, active assist, the joystick would actively push away from a detected obstacle. Previous research indicated that mobility efficiency was maximized when active assist was used (4). For this study, active assist was used. If the wheelchair was in danger of having a collision, a force was applied to the joystick along the steering axis that would make the wheelchair steer away from the obstacle (4). The magnitude of force was dependent on time-to-hit, angle between the velocity vector of the wheelchair and the edge of the closest obstacle, and the position of the joystick. The time-to-hit was the time it would take for the wheelchair to have a collision if the present course and speed were maintained. The angle between the velocity vector of the wheelchair and the edge of a nearby obstacle is illustrated as the angle θ in Figure 1.

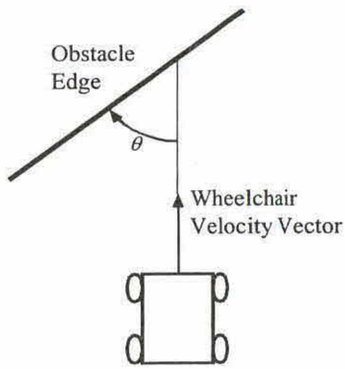

Figure 1. Wheelchair approaching an obstacle

METHODOLOGY

Instrumentation

The force feedback joystick had two axes of rotation - one for speed and the other one for steering (Figure 2). Encoders on these two axes provided information about the driver's desired speed and direction, while the rotations of the wheelchair wheels was used to determine the chair's

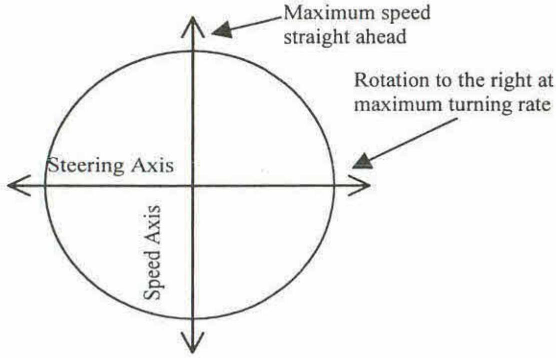

Figure 2. Joystick axes of rotation

position. Based on this information, a PC changed the compliance of the joystick when the wheelchair was in danger of colliding with an obstacle. A TE5650 interface board (Technology 80, Minneapolis, MN) in the computer was used to communicate between the software and hardware. This board provided force feedback by controlling a motor coupled to the joystick's steering axis. Computer software also determined the desired speed and direction of the wheelchair based on the joystick signals. Because the force feedback joystick was not directly connected to the wheelchair controller, the TE5650 board simulated the original wheelchair joystick. The wheelchair used for this study was a Fortress 770 power wheelchair (Fortress Inc., Clovis, CA).

Because the wheelchair used in this study did not have obstacle detection features, a virtual reality system (World ToolKit, CTC, Johnstown, PA) was used to develop virtual test courses. The position of the virtual wheelchair within a course was determined by the movement of the real wheelchair's wheels. The positions of obstacles in these virtual courses were known by the computer. A head-mounted display (virtual reality glasses) provided visual feedback to the subject.

Subjects

Five subjects participated in our study. Of these subjects, three were females and two were males. The subjects were aged 33 to 56 years, averaging 47.6 years (standard deviation 8.11). Four subjects had cerebral palsy; the other one had polio. All of the subjects had at least a year of experience using a hand-operated proportional joystick. Power wheelchair driving experience varied from 1 to more than 20 years. The average experience with a power wheelchair was 8.4 years with a median of 5 years. The subjects used their power wheelchair from as little as 2 hours a day to 16 hours a day.

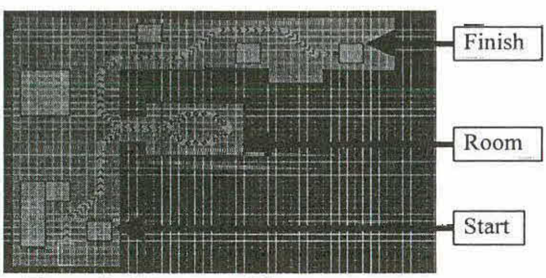

Figure 3. Diagram of Test course.

Testing and Evaluation Methods

The following procedure was followed in a lab using a virtual reality system. First, the test subjects had an opportunity to discuss the procedure. Second, while the subjects sat in their own wheelchairs, the position of the force feedback joystick was adjusted to the comfort of the user by a clinician experienced in positioning joysticks. Third, the subjects had an opportunity to become accustomed to the system by navigating a practice course, both with and without force feedback. This practice period lasted 10 to 15 minutes. Fourth, an investigator demonstrated how to navigate the test course (Figure 3). Fifth, the subjects navigated through the test course eight times. Half the trials were with the force feedback and the other half without the feedback. For quantitative data, the parameters recorded for each subject on the driving course were 1) total elapsed time to complete the course; 2) total number of collisions with the virtual obstacles; 3) distance traveled in inches; 4) average speed; 5) whether or not the subjects made one successful turn in a room; and 6) the time spent in the room. Finally, a post-interview lasting about fifteen minutes was given to each subject.

RESULTS

Table 1 shows the overall averages and standard deviations with, without, and both with and without the force feedback. This shows that the average speed was higher without the force feedback. The number of collisions averaged slightly higher without the feedback.

Force (Y/N)	Completion Time (secs)	Number of Collisions	Distance Traveled (ins)	Average Speed (ins/sec)
N	298.04 ± 137.13	9.78 ± 8.20	1094.18 ± 158.45	3.67
Y	304.84 ± 154.79	8.56 ± 7.92	1074.63 ± 86.59	3.53
Both	301.44 ± 146.27	9.17 ± 8.08	1084.41 ± 128.05	3.60

Table 1. Overall averages and Standard deviations

DISCUSSION

Four of the five subjects in this study had fewer collisions with the force feedback activated. The fifth subject, who had cerebral palsy, was the one who used his powered wheelchair the least. Being a relatively new powered wheelchair driver, one possible explanation for this result could be that since he was not familiar with a conventional joystick, adding the force feedback made it more unfamiliar to him. The other subjects had more experience using a conventional joystick and had better performance with the feedback. In conclusion, the force feedback joystick may be helpful for some wheelchair users, but further research is needed to obtain statistically significant results.

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POWERED MOBILITY DEVICE SKILLS TEST

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ABSTRACT

Beneficial Designs was asked by the U.S. Department of Justice to assist with negotiating a settlement between a retirement facility and a person who used a powered scooter for mobility. As a result, a powered mobility skills test was developed to assess the safety of a driver of a powered mobility device to self and others in a public or private multi-resident environment. The test consists of a required indoor test with 17 tasks that the user must complete in a controlled, safe manner, and an outdoor environment test with 5 tasks. The use of this test is considered a compromise between the safety of other ambulatory residents who could be severely injured by an unskilled power mobility device user, and the rights of other residents who use powered mobility devices.

BACKGROUND

Beneficial Designs was asked by the U.S. Department of Justice to assist with negotiating a settlement between a retirement facility and a person with a mobility impairment who used a powered scooter for mobility. The retirement care facility was concerned with the safety of its residents. The facility wanted assurance that the powered mobility user had a basic minimum skill set to safely operate the powered equipment in close proximity to other ambulatory residents. The plaintiff in this case wanted the right to use powered mobility, not only within the individual room units, but also in common areas shared with the other residents.

OBJECTIVE

As part of the settlement for this case, the U.S. Department of Justice requested that Beneficial Designs develop a powered mobility skills test to assess the safety of a driver of a powered mobility device (e.g., wheelchair, scooter) to self and others in a public or private multi-resident environment.

METHOD OR APPROACH

Beneficial Designs first sought the clinical expertise of Jean Minkel, a licensed physical therapist with numerous years of mobility training experience. Through contacts with fellow members of the International Organization for Standardization (ISO) Wheelchair Standards committee, information was obtained on tests used in other countries, including: Austria, France, Germany, Japan, Netherlands, New Zealand, Scotland, Spain, Sweden, and the United Kingdom. Rehabilitation centers in the U.S. were contacted to gather information about existing tests and publications pertaining to mobility training (1-5). This research revealed that an appropriate test did not exist in the U.S. and that there was a need to develop a test to assess a user's powered mobility skills.

RESULTS

A powered mobility skills test was developed for indoor and outdoor environments. The test is designed to be administered in approximately one hour by a licensed physical therapist, licensed occupational therapist, or a RESNA certified assistive technology provider or assistive technology supplier. The test is to be conducted in or around the multi-resident environment in which the user will be using the mobility device.

This test is divided into two parts: 1) required indoor powered mobility skills test, and 2) outdoor environment powered mobility skills test. All powered mobility device users must complete the indoor test. The outdoor test should be conducted only if appropriate.

Each test consists of a set of tasks (Table 1). The powered mobility device user must perform the tasks that are applicable to the particular multi-resident environment. If the task is not appropriate for the multi-resident environment, then the mobility device user is not required to complete that task. For example, if the multi-resident environment contains corridors, but no elevators, then the mobility device user must complete the indoor corridor task, but not the indoor elevator task.

Table 1. Tasks for the Required Indoor Environment and the Outdoor Environment

Required Indoor Environment		Outdoor Environment
Transfer out of and into mobility device	Approach/depart table	Negotiate sidewalk environment
Mobility device components	Operate:	Negotiate street crossing environment
Control operation	door that pulls to open	Negotiate standard exterior ramp
Driving in a corridor	door that pushes to open	Negotiate single step/curb transition
Controlled turning	fire door with release bar	Public or private transport lift
Turning around with a backing maneuver	pocket door	
Maneuvering in a congested area	switch-actuated door	
Maneuvering in a tight area	Negotiate indoor ramp	
	Negotiate elevator	
	Lift in building	

Instructions and Scoring

The examiner provides clear instructions to the mobility device user using a given script. The mobility device user is allowed to practice the task if desired, and then to demonstrate the task to the examiner.

Each **element** of the task is scored as follows:

4 **Independent** – Can complete safely without assistance. (Pass)

3 **Controlled Dependence** – May need significant physical assistance to complete, but is fully able to instruct another person in the type and amount of assistance that is needed. This instruction can occur verbally, with a communication device, or by use of an instruction card. (Pass)

2 **Close Supervision** – Requires significant supervision or verbal cues for safety of self or others in the environment. Does not or is not able to request assistance when needed. (Fail)

1 **Needs Further Training** (Fail)

The mobility device speed should not exceed normal walking pace (2-3 ft per sec) when around pedestrians regardless of the environment. On sloped surfaces (ramp, curb ramp), the speed may exceed walking pace when traveling down the slope; however, the rider should be in control and prepared to stop at any time. When turning corners, the mobility device user should stop at the corner to look for pedestrians, or proceed slowly making a wide turn.

Each **task** is scored as follows:

NA Not applicable to environment or did not test

Pass Demonstrates ability to safely perform task or negotiate environment in a controlled manner, considering speed, positioning of mobility device, body position, surrounding objects, and pedestrians. All elements of the task receive a score of 3 or higher.

Fail Unable to demonstrate ability to safely perform task or negotiate environment in a controlled manner or presents a safety risk to self or others in the environment. One or more elements of the task receive a score of 2 or lower.

If a person fails the test, he/she should be informed of the reason why and offered another test after an appropriate period. This period should be sufficient for the powered mobility device user to overcome the particular deficiency that resulted in the failure through additional training or practice under supervision. If the failure is a result of the user being nervous, query whether it is a result of the test administrator being too formal or officious. While the test has to be carried out in a serious manner, the user must be able to display that he/she can carry out relevant behavior in everyday situations. A test situation is not an everyday happening and a certain allowance should be made. Every effort should be made to make sure the user feels relaxed.

DISCUSSION

The use of the powered mobility skills test is considered a compromise between the safety of other ambulatory residents who could be severely injured by an unskilled power mobility device user, and the rights of other residents who use powered mobility devices. Many other countries currently require a driver's license for powered mobility devices when they operate at higher speeds and are used in a roadway environment. Other countries, such as Scotland, have a powered mobility skills test to ensure that individuals operating the powered mobility device have the skills to safely operate as pedestrians in the outdoor environment where they must safely maneuver close to motor vehicles and cross streets. Powered mobility device skills tests serve as tools to ensure that individuals using powered mobility devices have the minimum skill set required to safely operate in standard indoor and outdoor environments.

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COMPARISON OF ENERGY CONSUMPTION AND MAXIMUM SPEED IN ELECTRIC POWERED WHEELCHAIRS

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ABSTRACT

Although electric powered wheelchairs are required to be tested for safety to meet FDA requirements, the information about these tests is often not available to the eventual users of the wheelchairs. Two of the most important ANSI / RESNA tests administered to an electric powered wheelchair are the Determination of Energy Consumption and Determination of Maximum Speed, Acceleration and Retardation. The goal of this study was to determine if a correlation exists between the variables recorded during these two tests, and if there are significant differences among some of the most popular electric powered wheelchairs on the market today. It was determined that a correlation does exist between the maximum speed and the energy consumption of the wheelchairs studied, and that there are significant differences ($p < 0.05$) among the different electric powered wheelchairs. This research will lead to a better understanding of the wheelchairs available, to both the user and the clinician.

BACKGROUND

Although the safety and performance records of electric powered wheelchairs are required for Food and Drug Administration (FDA) approval of an electric powered wheelchair, the results of these tests are often not made available to the public. The reason for this is that there is no obligation by the manufacturer of the wheelchair to divulge this test information in their advertisements or in consumer reports. However in today's competitive market, electric powered wheelchair users demand these results when deciding which wheelchair to purchase (3).

The importance of the energy consumption of an electric powered wheelchair involves the amount of time and for what distance a wheelchair can run without recharging the battery (4). This information is crucial to the electric powered wheelchair user because he / she does not want to run out of power in any situation where a charger and the time for the batteries to charge is not available.

A comparison of the energy consumption and the maximum speed of an electric powered wheelchair is important because if a correlation can be determined between the two values then the electric powered wheelchairs that are available can be compared to give the consumer and the clinician as much information as possible when selecting the proper wheelchair.

RESEARCH QUESTION

The goal of this study was to determine if a correlation was present between the energy consumption and the maximum speed of the fifteen selected electric powered wheelchairs. By determining if a correlation is present between these two variables it could be determined whether one model of electric powered wheelchairs is more suited for a specific lifestyle of user than another wheelchair.

METHODS

To complete the comparison study fifteen electric powered wheelchairs were tested, all in their original factory configuration. Five different models of electric powered wheelchairs were tested, using three wheelchairs of each model: 1) The Everest and Jennings Lancer 2000, 2) The Quickie P200, 3) The Invacare Arrow Action Storm Series, 4) The Permobil Chairman, and 5) The Pride Jazzy.

In order to determine the theoretical range (km) of each wheelchair, which is the amount of distance an electric powered wheelchair can travel on a charged battery, a Cruising Equipment Company watt-hour meter was used. The watt-hour meter was connected to the battery of the wheelchair and tested according the ANSI / RESNA Standards – Part 4 (1). This test incorporated driving the wheelchair around a square test track with a length of 54.5 m. The theoretical range of the wheelchair was then determined.

$$R = \frac{C * D}{E * 1000}$$

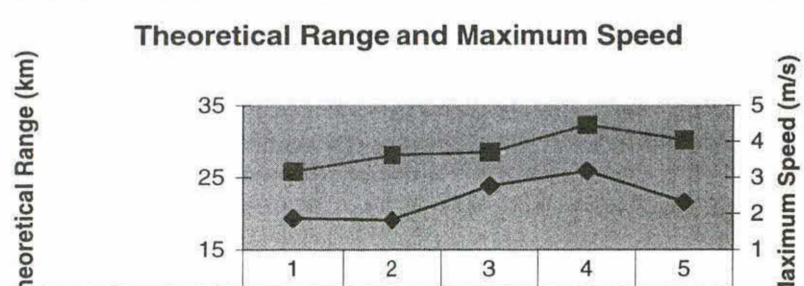
Where:
R = Theoretical range in kilometers
C = Capacity of the battery in ampere hours at five hour rate of discharge
D = 20 times the length of the center line of the test track in meters
E = Ampere hours used during the test as measured by the watt-hour meter

Because the capacities of the batteries of each chair are the same the ranges can be compared to each other.

To determine the maximum speed of the wheelchair a trailing wheel was used and testing was done according to Part 6 of the ANSI / RESNA Standards (2). This trailing wheel consists of two wheels connected to an encoder that measures the number of revolutions that the wheels make. Taking into consideration the diameter of the wheel the maximum speed, and accelerations can be determined using a Matlab program.

RESULTS

The range of each chair as well as the maximum speed of each chair was calculated. Displayed in and Figure 1, are the means of each set of the three wheelchairs.



	1	2	3	4	5
Theoretical Range	25.8	28.1	28.5	32.3	30.2
Maximum Speed	1.87	1.82	2.77	3.18	2.32

Figure 1

A Nonparametric Correlation, which determines a correlation between two variables that are not normally distributed, was used. There was found to be a positive correlation between the maximum speed of the wheelchair and the theoretical range ($p < 0.05$). Therefore as the maximum speed of the wheelchair increases the range of the wheelchair also increases. Using a one tailed Analysis of Variance (ANOVA) there was also found to be significant differences ($p < 0.05$) between the different models of wheelchairs when their maximum speeds and their theoretical ranges were compared.

DISCUSSION

Analysis of a comparison between the energy consumption and the maximum speed of an electric powered wheelchair shows a correlation between the two test's results. The correlation is a positive one, which means that the energy consumption and the maximum speed of the chairs are proportional to each other. This implies that as the speed of the chair increases the distance traveled prior to battery discharge increases. There is also a significant difference found when the theoretical range or the maximum speeds of the wheelchairs are compared.

Because of these measured differences electric powered wheelchairs can be selected for an individual user to meet his / her specific needs. A wheelchair built for maneuverability will probably have front wheel drive and no need for a high maximum speed, which is apparent in the results being that the Permobil and the Jazzy are the only two front wheel drive chairs and are designed for maneuverability.

To pursue future work in this particular area it will be important to examine the energy consumption in comparison to the accelerations of the five different types of electric powered wheelchairs.

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YOUR MOVE: THE WISE INTEGRATED SYSTEM PROJECT

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ABSTRACT.

The WISE:*dx* integrated control system is a small electronic device enabling a physically disabled individual to drive a powered chair with a switch(es) or a joystick. It will also allow s/he to change the use of the same switches and operate other equipment. For example, it will allow someone to drive their powered chair up to a computer and operate the computer remotely via a built in infra red link using the same switch(es) or joystick. The system is very flexible and configurable to cope with the varying needs of a wide range of individuals. An important feature of the system is the ability to configure it for an individual using a PC computer. The programme guides the assessing professional towards setting up the most appropriate and efficient operating method for that person.

BACKGROUND

An Integrated Control System is a device that enables a person with physical disabilities to operate a range of technological assistive devices from a single access source (1). These include speech output devices to communicate, environmental control units to operate aids to daily living and powered wheelchairs for independent mobility. Each of these has its own operating system (keyboard, joystick, switches) and, generally speaking, independently controls each device. An Integrated Control System acts as an interface between the person's preferred method of access and a range of off-the-shelf technological assistive devices. For example, it enables a person who has very limited physical movement, who could perhaps operate one or two switches, to drive a powered chair and operate other existing aids to living, remotely and independently, with the same switch. Integrated Control Systems reduce the amount and type of switches required to access a range of equipment.

Integrated Systems have been in existence for a number of years (2), most have been tailor-made for particular individuals. However, they can lack the flexibility required of a manufactured system that must be readily adaptable to meet the needs of a range of different people with different abilities and requirements.

A previous project, the "8 Plus Eight" (3), designed by the author, is an Integrated Control System manufactured and marketed by a company. It was designed to enable a powered chair to be driven with one or two switches, and incorporated a number of switch-scanning options. In addition it was designed to allow environmental control units and communication aids to be accessed independently with the same switch. Over the years a number of modifications were made following experienced-based feedback from people using the system (4).

Bespoke systems also remained necessary for individuals requiring more sophisticated ways to drive a powered chair, using, for example a joystick which could also access a communication aid as if it were a single switch (5).

STATEMENT OF PROBLEM

Experience with integrated system design for individuals, as previously outlined, has identified two key issues which are vital to the use and effective implementation of integrated systems. The first issue relates to the functionality and flexibility of the system to meet user requirements.

The second issue is an assessment issue for a rehabilitation professionals involved in implementing and configuring an integrated system for their client. These are summed up as **Flexibility** and ease of **Configuration**

RATIONALE

An effective integrated system enables a person to access different equipment independently without compromising their most efficient accessing skills with each device.

A flexible system is important for a number of reasons:
(a) Increasing available options, particularly switch-scanning options, maximises the "fit" between the system and individuals' specific needs so that the best of their abilities are realised.
(b) The system can be adapted to changes in individuals' requirements over time.
(c) The system needs to be able to act as an adaptable interface between an individual's preferred method of access and a *changing* variety of existing third party assistive technology aids.
(d) A wide range of individual needs must be met for commercial production of the system to be viable

The consequence of a very flexible system is the complexity of configuring the system to meet individual needs and abilities. Although a rehabilitation professional would carry out this task at a local level, this person may not be completely familiar with special controls for powered mobility, integrated systems and the range of options available. The rehabilitation professional may also be unaware of the relative merits and differences between options.

DESIGN AND DEVELOPMENT

The WISE integrated system project has been designed containing two distinct parts: an electronic hardware system for use by the client and an easy to use PC based programme for use by the assessing rehabilitation professional.

(a) The hardware system

The hardware focuses on providing a comprehensive range of switch-scanning routines for powered mobility. This enables a wide range of individuals with different abilities to use the most appropriate method of operation for their needs. The system also offers the user different ways of accessing other technologies and includes features such as a built in "learnable" infra red transmitter based on a GEWA prog III module, up to six outputs for direct connection to devices such as a communication aid, an attention calling buzzer and audio feedback during scanning.

(b) The Configuration software

To enable the system to be configured easily and efficiently a software package, for use in a Windows environment on a PC computer, has been developed. This acts as an assessment tool and assists a rehabilitation professional in configuring the system for an individual as appropriately, but as easily, as possible. The professional should not require extensive experience of special controls or integrated systems, the aim being that the software presents a logical procedure for choosing the most appropriate options to meet the needs and physical abilities of individual users.

The software can work independently of the hardware enabling a decision to be made as to the suitability of the system to meet the need without having to obtain the hardware. If the hardware system is required then the "optimised" configuration can be downloaded from the PC into the actual device through a serial link.

The software contains a number of functional components including an optimisation guide, a simulator and plenty of help. For very experienced professionals configurations can be further customised using the advanced customisation option.

EVALUATION

A steering group of professionals from different backgrounds has been overseeing the project during the last year. More recently the prototype system and in particular the PC software has been presented to various focus groups, including users, for feedback and comments. This has enabled changes to be made during the prototype stage of the project. The software is currently being more formally evaluated. Twelve professionals with backgrounds in four different areas of assistive technology are answering a questionnaire relating to the effective use of the software.

SUMMARY

A flexible integrated system has been designed and built that meets the needs of a wide range of people with physical disabilities. An important feature of the system is the ability to programme the device (i.e. configure it for an individual) using a PC computer. The programme guides the assessing professional towards setting up the most appropriate and efficient operating method for that person. In effect this software contains "expert knowledge" in the use of switches for powered chair mobility and integrated systems that has been gained over the last 10 years through experience.

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SOFTWARE TO AID IN CUSTOM WHEELCHAIR DESIGN IN PERU

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ABSTRACT

A small program is offering the first special seating services in Peru. The program produces low-cost wheelchairs and seating systems, using local resources and labor. Software has been written to facilitate the design of these wheelchairs, each of which is custom designed and built according to the needs of the user.

BACKGROUND

Basic assistive technologies, such as special seating systems and augmentative communication equipment, are largely unknown in Peru, as in many other developing countries. Because the vast majority of Peruvians with disabilities cannot afford imported wheelchairs or special seating systems, Peruvian rehabilitation professionals have very little experience or training applying fundamental seating and positioning strategies and equipment. Because the Peruvian rehabilitation professionals have limited knowledge of this field, they generally don't realize that basic seating and positioning systems can be developed using locally available materials and labor.

In 1997, the authors collaborated in developing a small six-month project in Lima, Peru to build wheelchairs with special seating systems to be donated to abandoned Peruvian children with cerebral palsy and special seating needs. The goal of the project was to gain experience building wheelchairs with special seating systems using local resources, and thus develop a mechanism through which low-cost wheelchairs with special seating systems could be made available to the public. Through the process of building the donated wheelchairs, basic seating and positioning knowledge, as well as fabrication methods, were developed. After the six-month project ended, the Peruvian professionals were able to apply the techniques and later opened a private practice, which includes the only seating and positioning clinic currently operating in Peru.

The majority of wheelchairs in Lima, Peru are built by local artisans who specialize in this craft. The designs they use are typically copied from traditional sling-seat wheelchairs. Hotchkiss (1) designed the Whirlwind, a wheelchair especially well suited for conditions in countries with limited resources. The Whirlwind compares very favorably with the traditional sling-seat wheelchair design commonly built in Peru. Specifically, the Whirlwind is lighter; more flexible, thus able to withstand harsher conditions; simpler and faster to build, therefore cheaper; and easier to maintain.

The first wheelchair produced during the initial six-month project used adjustable mounting hardware to mount a wood and foam seating system to a Whirlwind wheelchair. However, the mounting hardware proved to be one of the most time consuming components of the entire system to build. Therefore, time and expense increased unnecessarily. Because the wheelchairs were built in a custom manner, it was decided that the dimensions of each wheelchair could be designed to accommodate the dimensions of the desired seating system, thus eliminating the need for highly adjustable mounting hardware. A seating simulator was built so that the desired dimensions of the seating system for a given individual could be known before construction was begun on the wheelchair. The wheelchair could then be built so that the seating system components mounted flat against the wheelchair tubes. Planar adjustments could easily be made to accommodate length discrepancies or growth, and small angular adjustments could be made by bending the tubes.

To accommodate a range of backrest angles and simplify construction, subsequent wheelchairs were built using the design for the Whirlwind I-Africa, a variation of the original design (2). This wheelchair had a unique advantage in that the seat tubes were not linked to the backrest tubes. Thus, the backrest tubes did not have to be at right angles with respect to the seat for the wheelchair to fold. This characteristic facilitated custom design changes of the wheelchair frame to accommodate a wide range of seating systems without the need for traditional mounting hardware.

STATEMENT OF PROBLEM

The process of custom designing each wheelchair frame to specifically accommodate a custom seating system greatly simplified wheelchair construction because it eliminated the need for traditional mounting hardware. Unfortunately, this method greatly complicated the planning process, as each wheelchair had to be custom designed, and a change in one dimension could affect many other dimensions as well. For instance, if one wanted to change the seat angle, the lengths of all the tubes and the angles and locations of tubular bends would all have to be recalculated. This process proved to be too complicated once the original six-month project was concluded.

After the initial six-month project, due to production problems, an outside wheelchair shop, owned and largely operated by people with disabilities, was contracted to build the actual wheelchairs. The new shop produced high quality work, but did not have experience designing the Whirlwind wheelchair, and thus produced a more traditional model, which could not accommodate much variance in seating systems without the use of adjustable mounting hardware. None-the-less, several wheelchairs with special seating systems were built and sold commercially.

RATIONAL

The authors decided that a simple method of designing a custom Whirlwind I-Africa wheelchair with the proper dimensions to incorporate a custom seating system was needed in order to improve quality and reduce cost. Neither the original paper and calculator design method nor a simplified method of laying out the design in masking tape on a plywood template proved successful once the original six-month project ended. It was decided that a software program could be written to assist the Peruvian team in wheelchair design, once the end measurements (lengths and angles) were taken from a seating simulator used to find an optimal seating position.

DESIGN

A DOS-based program was written in C to aid in the design of custom wheelchairs with incorporated seating systems. As seen in Figure 1, the program user has to input data such as seat angle, seat length, seat cushion thickness, backrest angle, backrest length, backrest cushion thickness, knee angle, length to heel, armrest height, and seat width. These dimensions can be tested with a seating simulator before being duplicated in the wheelchair design. Additional wheelchair parameters such as radius of tubular bends, diameter and fork-angle of front casters, and rear wheel diameter can be changed to accommodate the supply of locally available materials and special design considerations.

As the desired dimensions are entered, the program calculates the dimensions of the wheelchair frame components and displays the resulting wheelchair frame design on the screen. Once the program user is satisfied with the design, he or she may view the lengths and angular dimensions of each tubular component of the wheelchair displayed on the screen. The actual tubes may then be cut and bent to the proper dimension. The program will also show the proper assembly of the tubes and other components so that they may be brazed together at the proper angles and positions. If the dimensions are faithfully followed, the resulting wheelchair will accommodate a seating system with the dimensions entered by the program user.

EVALUATION

At the time of this writing, one wheelchair was built successfully using this software. The resulting dimensions matched those of the desired seating systems and the wheelchair is being successfully used. Because of the simplified construction of the Whirlwind I-Africa wheelchair, the team was able to sell the wheelchair for $200, a savings of $70 over the price of a traditional-design wheelchair produced at the same shop. Although the mechanics who built the wheelchair were at first skeptical about its strength relative to a traditional-design wheelchair, they were quite happy with the end result. Another client is currently being evaluated to receive a similar wheelchair with special seating system, and the amount of business the clinic is getting is gradually increasing as more people hear about special seating.

DISCUSSION

The future of this project will depend on many factors. First of all, it is important to educate other Peruvian rehabilitation professionals about the benefits of special seating and positioning. Though many Peruvians have difficulty affording such wheelchairs, it is expected that the need for special seating will continue to increase as more people know of its availability and benefits. It is also important to refine fabrication techniques to reduce fabrication time and improve quality. It is important for the Peruvian team to evaluate the quality of their seating interventions, and gain more experience with special seating and positioning application. Finally, with feedback, the software program to help design the wheelchairs can be improved to be more easy to use as well as offer more design options. Of course, if this initial effort proves successful, similar programs could be implemented in other developing countries.

Figure 1. Software user can change design parameters and see the resultant wheelchair design on the screen.

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SUSPENSION SYSTEM FOR AN ALL-TERRAIN WHEELCHAIR

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ABSTRACT

A new type of wheelchair suspension is being developed at the State University of Campinas, Brazil. The aim of this suspension is to improve the accessibility and the use of wheelchairs in indoor, outdoor, and off-road environments, without the need of special architectural modifications to overcome obstructions and at reasonable costs.

BACKGROUND

The conventional wheelchair is comprised of four ground engaging and narrow width wheels. Two of them with large diameter are mounted on an axle positioned below the seat portion of the chair. The other two with smaller diameter (usually castor wheels) may be positioned on front or behind the large ones. The occupant of the wheelchair is seated in a fashion such that his/her lower legs will be generally perpendicular to the ground. The wheelchair can be powered manually, by the occupant or another person, or by a motor (e.g. electrical, pneumatic or hydraulic).

The user of this type of wheelchair is faced with a great number of problems when using it in outdoor or off-road environments. There are some instabilities caused by a high position of the center of gravity, or CG (i.e. the wheelchair may topple over when negotiating steep grades, or sideways when laterally traversing a steep incline). Besides these problems, the conventional wheelchair faces additional difficulties to move on uneven surfaces and overcome environmental obstructions (e.g. obstacles in the path like steps and small rocks) or architectural features (e.g. stairs, steep ramps, and curbs). To overcome these obstacles, architectural modifications must be done (e.g. standardized ramps, special elevators, large doors and corridors, etc). While in developed countries these modifications have been done for many years, based in laws and standards, in developing countries the situation is completely different. A common problem reported by wheelchair users in these countries is the nonexistence of architectural modifications to improve their accessibility to buildings, parks, and gardens or even to cross the street. The costs of these modifications are very high and there is always an unanswered question: "*Who will pay the bill?*". The governments of these countries can not impose the modification of the architectural features in a short period of time and, probably, they will have to pay great part of the costs. A cheapest and fastest solution is to modify the wheelchairs to improve its capabilities to overcome obstacles and thus to increase the user's quality of life (1).

Researchers have proposed the use of tracks, suspensions with springs and dampers, tricycle configurations, lower center of gravity, etc. Nevertheless, the more innovative design changes were proposed by Wellman et al. (2) and Kamen et al. (3). The first approach consists on the use of a wheelchair which has been fitted with two 2 degrees-of-freedom mechanisms (similar to legs) to overcome common obstacles like steps and curbs. Nonetheless, the use of this kind of mechanism can be dangerous for the user and people nearby (some accident may occur). Furthermore, the wheelchair may topple over when negotiating obstacles due to the inclination of the wheelchair body. The second approach has undeniable functional capabilities. The INDEPENDENCE™ 3000 IBOT™ Transporter has the capability to swivel up and down curbs and stairs and even balance using only two wheels. Nevertheless, this vehicle will be priced in the range of US$ 20,000 to US$ 25,000, and requires a very sophisticated hardware to control and optimize the CG position of the wheelchair. Of course this price range is prohibitive for developing countries. It is necessary to find a not so sophisticated and cheaper solution adequate for this kind of market. The price should not be much higher than the price of currently available motorized wheelchairs.

RESEARCH QUESTION

To design and evaluate a new suspension system for an all-terrain wheelchair that provides it the ability to overcome obstacles like steps, to redistribute the weight among the wheels, and to stabilize the user's position. Also are considered the costs, functionality, robustness, and reliability of the solution.

METHOD

Initially, mechanical design studies were made to determine the locomotion mode of the wheelchair in outdoor and off-road environments. Following the criteria mentioned above, the candidate locomotion concepts were compared and two modes were selected: the rolling mode, based on the use of wheels, and the hybrid mode, based on the use of wheels and legs/arms (2). The rolling mode is preferred because it is simple, robust, cheaper, and the background about it is large. The hybrid mode has more mechanical and control complexities, due to the number of simultaneously active degrees of freedom, implying high costs and energy consumption which decreases the autonomy of the vehicle.

The second decision was the choice between the use of castor or steerable wheels. Castor wheels are not adequate in off-road environments because in this kind of environment it is better to have steering and driving control of all wheels. Regarding the number of wheels, state of the art analysis shows that the best compromise between complexity and performance is the six-wheel drive configuration (4). This configuration has the highest climbing performance when compared to four and eight-wheeled ones. Due to the limited length of the wheelchair the use of four corner steering system (i.e. steering wheels only on front and rear axes) was chosen. This choice avoids high slippage of the wheels and allows the use of the Ackerman geometry to control the steering of the wheelchair (5). One such system is the "*Pantograph*" linkage suspension developed at the Jet Propulsion Laboratory (JPL-NASA, USA) for planetary surface exploration (6). Unfortunately, to use this kind of suspension, it is necessary to know the exact position of the CG of the vehicle body and the side linkages should lie on an axis passing through this position. This requirement is impossible to fulfill in a wheelchair, where the user should not have restrictions of movements and each one has different size and weight, factors that modify the position of the CG.

One possible solution could be the use of motors and gyroscopes instead of differential linkages to connect the wheelchair body and the suspension. Thus, the motors can incline the wheelchair body, relocating the CG, and annulling the momentum on their axes caused by the weight vector. This solution is similar to that adopted by Kamen et al. (3). Nonetheless, in this case, it requires that the motors to be always active, even when the wheelchair is on plane surfaces, to compensate the "*undesired*" position of the CG. This behavior of the motors consumes more energy, reducing the autonomy of the wheelchair. Many motors and sophisticate control techniques (active systems) that require many processors and energy consumption are expensive. Another approach is to use only mechanical elements (i.e. springs and elastic members) to produce a passive system. This solution is preferred, however, passive elements can suffer when climbing an obstacle. In 70's suspension using articulated (7) and independent suspended wheels (8) were developed to absorb irregularities in the terrain. The second approach provides a better transmission of forces between the suspension system and the body of the vehicle and less motions of the body on obstacles. It consists of a pair of parallel links contents each one three independently suspended wheels. Each of the corner wheels is maintained in contact with the ground by a shock absorber-spring assembly. The proposed solution is a combination of the six-wheeled *Pantographic* and of the independent suspended wheels approaches. The links between the wheels are elevated above them. These links create pivots at the corners and make it possible to include wheel struts, for steering. The middle wheels are connected directly to the body. This configuration allows each side of the suspension to articulate independently while the wheelchair maintains an average pitch angle between left and right sides, and reduces the roll motion reducing the motion of the body for any single wheel with a large perturbation.

RESULTS AND DISCUSSION

Mechanical design studies were made to determine the best suspension configuration that can provide an all terrain capability for wheelchairs at reasonable costs. A simple option to reduce costs is the use of mechanical elements – passive systems. This suggests that the proposed solution is cheaper compared to others in the market. This is especially relevant in developing countries. Modeling and simulations of the suspension, using the software MOBILE (9), are been done to evaluate the efficiency and to improve the design. Through the results it will be possible, e.g., to define the best relation between number of drive motors and climbing performance, wheels diameters, seat position, velocities on obstacles etc. Future plans include building a prototype and investigating the behavior of the wheelchair in real environments.

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SAND CRUISER

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ABSTRACT

Current beach wheelchairs lack the ability of self-propulsion. The Sand Cruiser is an innovative wheelchair designed to give disabled people independent access to beaches and parks. The Sand Cruiser is a light, portable, easy to assemble wheelchair powered by a gasoline engine. The Sand Cruiser was designed and constructed by a team of engineering students at California State University of Los Angeles.

BACKGROUND

Wheelchair manufactures have paid little attention to the development of recreational equipment for the disabled. Current outdoor wheelchairs are highly priced and still limited in function and quality. Existing beach wheelchairs lack the ability of self-propulsion. Patients at Rancho Los Amigos National Rehabilitation Center desired a self-propelled, all terrain wheelchair, so the need to design a more sophisticated and ingenious wheelchair was necessary.

STATEMENT OF THE PROBLEM

The objective of this project was to create a powered wheelchair that could be used in sand or rough terrain. The following criteria were established for the design:

- To make the beach wheelchair weight less than 100 lb.
- Maximum load capacity of 250 lb.
- Self propelled
- To be able to access beaches and parks
- Small enough to fit in a car
- Easy to assemble

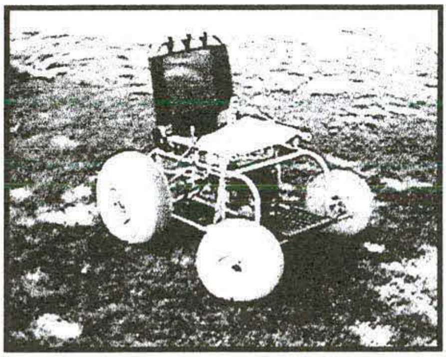
The chair must also be designed to meet all the ergonomic standards, needs, and safety requirements of wheelchair users. The ultimate goal of the chair is to provide patients a safe device that will give them the freedom of mobility and independence in sand and rough terrain.

RATIONALE

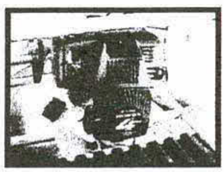
Before we started to design our wheelchair, we had to define who was the intended user of the device. We set the standards for patients who have strong to moderate upper body strength. The wheelchair user must have the ability to operate a powered wheelchair. Choosing the propulsion method was quite challenging. An electrical motor was a natural candidate, but the weight of the motors prevented a person from lifting the chair. We wanted to avoid the problem of charging the batteries, or running out of battery power that could leave a person stranded on the beach. From a manufacturing point of view, the cost of electrical motors, batteries, and chargers can range from $1000 to $4000 depending on the power capabilities. We choose a gas engine because they are lighter, cheaper, and easier to fix than electrical motors. We choose 6061 aluminum for the frame, which has strength, good formability, weldabiltiy and the corrosion resistance needed in a salty moist environment. Our final design was built with pneumatic wheels for suspension, an aluminum frame, a steering mechanism, and a gas engine.

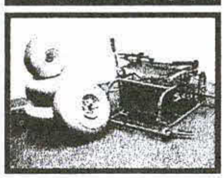
DESIGN

The Sand Cruiser prototype was built in the spring of 1999. Wheelchair user Fidel Valenzuela successfully tested the chair on the sand at Long Beach, California. The Sand Cruiser has the following characteristics:



- Weight of chair: 49 lb (1)
- Base: 30" x 19" (1)
- Height: 17" (1)
- Wheelbase: 28" (1)
- The chair can withstand a maximum weight of 250 lb. (1)
- The Sand Cruiser is designed to meet all the ergonomic standards and sizes of the average adult person. (2)
- Steering System - The steering mechanism allows the user to drive the wheelchair with one hand. The steering handle is placed on one side to allow the other side to be free of obstacles while transferring from one chair to the other. (2)
- Transfers – The front of the wheelchair is wide and free of obstacles to allow users easy transfers from regular wheelchairs into the Sand Cruiser. (3)
- Safety - The wheel chair is wide enough to prevent tipping with maximum forward tipping angle of 30°, rear tipping angle of 30°, and a side tipping angle of 27°. (3) (4)
- 1-Hp Gas Engine- A lightweight Honda engine powers the wheelchair. The engine provides a maximum cruise speed of 7 mph and ride time for up to 2 hours with a full tank of gas. (5)
- Transportation - The Sand Cruiser can easily fit into most trunks of automobiles. The chair can easily be disassembled into a compact unit ready for transport.





DEVELOPMENT

Further development of the beach wheelchair is still in process. I am currently employed by Schober's Machine and Engineering, a manufacturer that is developing the Sand Cruiser as a product line. We have met with other wheelchair manufacturers such as Comet Industries, Colours Inc., and Merits Health Products. Schobers is developing two versions of the chair. The first version of the chair will be a design similar to the Sand Cruiser, aimed for personal use. The chair will be kept light, portable, and inexpensive. The second model of the chair will be a deluxe version designed for hotels and resorts. The wheelchair will be equipped with a transmission, an electrical starter for the engine, a silencer, and more added features such as adjustable foot rests, recliner, and a swivel chair for easier transfers.

EVALUATION

The Sand Cruiser met the standards set at the beginning of the project. Still, further design must be done to improve the quality of the beach wheelchair. The steering mechanism must be improved to reduce steering effort and provide smaller turning radius. A reverse and neutral shift is a be a priority in the next wheelchair design. The prototype consists of a forward gear only. Mounting of the motor and transmission are being redesign to provide better support. Also, the frame is being redesign to provided a more appealing product for wheelchair users.

DISCUSSION

The need for a reasonably priced self-propelled beach wheelchair has been established. Current outdoor wheelchairs are costly and still limited in quality and performance. The Sand Cruiser enables wheelchair users to independently ride on the beach. We provided a gas-powered engine to avoid the heavy weights of batteries and components found in electrical motors. The dimensions of the chair are safe and comfortable in order to provide good ergonomics and prevent tipping of chair in uneven terrain.

The potential for the chair to become a commercially liable product is now being studied and further researched. Schober's Machine and Engineering has a design team working on two prototypes. One model of the chair is a low cost portable unit aimed for active wheelchair users. The second model of the wheelchair is aimed for recreational areas such as beaches, parks, hotels, and resorts.

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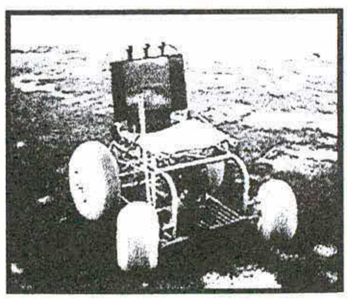

DEVELOPMENT OF A PROTOTYPE BUMPER SYSTEM FOR POWERED WHEELCHAIRS

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ABSTRACT

Powered wheelchair users engaging in active lifestyles have created a need for bumper systems that will protect the occupant and reduce damage to wheelchair components and the surroundings. A prototype bumper system was designed, constructed and evaluated. The system consists of a footrest hanger incorporating a parallelogram linkage with energy absorbing elements and a footbox that slides over the existing footrests. Laboratory testing showed that the system reduced the peak forces by approximately 40% in a simulated 3.6 mph collision. The prototype system was attached to a wheelchair and evaluated for two months. Observations indicated a diminished frequency of damage to the legrest components.

BACKGROUND

The advent of more active lifestyles, particularly among teenagers and young adults, has increased the possibility of collisions between powered wheelchairs and other objects. The footrests are usually suspended in a cantilever manner from the chair frame and thus are particularly vulnerable to collision damage. In addition, there is the potential for occupant injury as well as damage to the object being struck. The ANSI/RESNA footrest impact load test requires that footrests survive a 1.0 m/s impact at a 45° angle (1). Much greater velocities are routinely encountered in wheelchair sports, such as motor soccer and football. In recent experiments, a wheelchair with a simulated occupant was impacted into an instrumented barrier at velocities between 4 and 7 mph (2). For a 315 lb. wheelchair system, peak forces at 5 mph (2.24 m/s) were 470 lbs.

STATEMENT OF THE PROBLEM

Increasing numbers of powered wheelchair users are participating in sports and other activities where contact with other wheelchairs or the surroundings are inevitable. A wheelchair with an occupant can weigh in excess of 300 lb. and travel at speeds of up to 7 mph. Collisions can result in personal injury, wheelchair damage, or damage to the surroundings.

RATIONALE

Development of an energy absorbing bumper system will protect the occupant's feet and lower the peak forces in the footrest hangers; reducing the potential for both injury and wheelchair damage. Furthermore, shaping the impacting surface can reduce damage to the object being struck.

DESIGN

The following major design goals were established. The bumper system should withstand a 5 mph impact of a 315 lb. wheelchair system at 20° from the frontal direction without permanent deformation of the footrests. The system should protect the occupant from injury and provide protection to the object being impacted. The functionality of wheelchair should be maintained, including use of the footrests if a footbox is not present. Access into the wheelchair should not be impeded. The bumper system should easily attach using simple hand tools without irreversible modification of the wheelchair.

DEVELOPMENT

Several preliminary designs were developed and evaluated. The final design consisted of two components: a modified footrest hanger incorporating a parallelogram linkage with energy absorbing elements and an integrated footbox that slides over the existing footrests (Figure 1). In the parallel linkage, the original footrest mounting bar forms the base of the parallelogram. An extension bar is used to mount the footrest to the wheelchair frame. A cylindrical energy absorbing element is mounted interior to the parallelogram. When a load is applied to the footrests, the parallelogram deforms and the cylindrical element is compressed. The footbox consists of an impact barrier and a base section. The base is designed to slide over the existing footrests. The base and barrier assembly allows ½ inch of relative motion in both lateral and frontal directions. Foam placed between the barrier and base absorbs energy during an impact and returns the barrier to its original position when unloaded. Although designed specifically for an Invacare Storm series wheelchair with a Tarsys system top section, the design features of the bumper system are applicable to other powered wheelchairs.

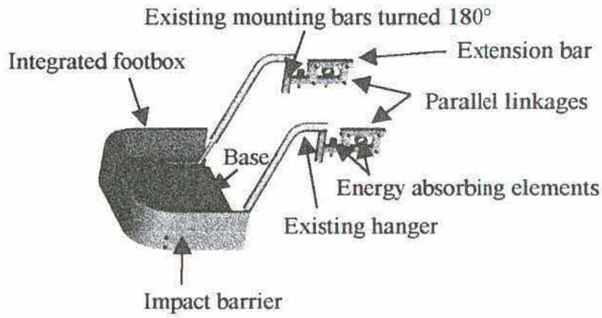

Figure 1. Prototype Bumper System

EVALUATION

Static tests were conducted to establish load-strain relations. Strain gages were attached to the footrest system at 12 locations where calculations indicated that the largest strains would occur. The instrumented footrests were mounted vertically on a table, so that free weights could be used to apply frontal loads of up to 200 lbs. Three conditions were evaluated: the original footrest system, the original footrests with the parallel linkage mounting and the complete system of the parallel linkage and the integrated footbox. These static results were used to calibrate the impact tests. Dropping a 25 lb. weight from a height of 11 inches generated an impact loading. A storage oscilloscope was used to capture the peak strain values. Figure 2 compares the peak strain at 2 locations for each of the 3 footrest/bumper configurations, normalized to the original footrest system. Since the force-

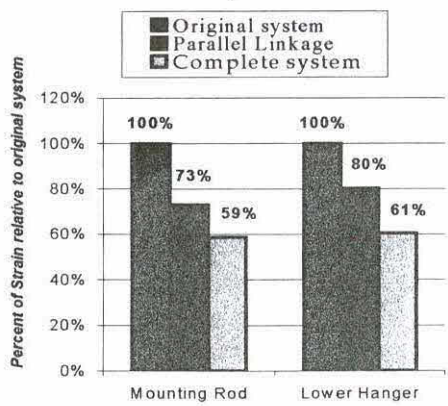

Figure 2. Effectiveness of bumper system in a 25 lb. drop test

strain relationship was linear, Figure 2 also represents a comparison of the peak forces. The parallel linkage alone reduced the peak force at the mounting bar by 27%. Adding the footbox to the system reduced the peak force by a total of 41%. For a position on the lower hanger just above the footplate, the reductions were 20% and 39% respectively. Comparing the force levels for the original footrest system with those reported by Hoffman et al. (2) indicated that the drop test simulated a collision velocity for a 315 lb. wheelchair system of about 3.6 mph (1.61 m/s).

Field testing of the modified footrests with the parallel linkage consisted of a 2 month period of full time use by a 210 lb. male subject. The integrated footbox system was used intermittently during this period for specific recreational activities. Wheelchair repair logs for the prior year indicate a legrest repair/adjustment frequency of approximately 1-2 times/month. No legrest repairs/adjustments were required during the field test period. Preliminary observations using the full system in contact wheelchair sports indicate a diminished frequency of damage to the wheelchair legrest components and reduced translation of impact forces to the user's body during frontal collisions.

DISCUSSION

A prototype bumper system has been designed, constructed and evaluated in both laboratory and field tests. All design goals were essentially met. Laboratory drop tests were equivalent to about a 3.6 mph frontal impact of a 315 lb. wheelchair system. The tests were terminated at this level to insure that an undamaged prototype would be available for field testing. The parallel linkage only responds to frontal forces. Additional tests are required to determine if the prototype can achieve the 5 mph frontal impact design goal. Oblique impacts would involve both frontal and lateral velocity components. The footbox will absorb some energy from lateral impacts. Peak forces have been shown to be approximately proportional to velocity (2). For a 20° impact at 5 mph, the lateral velocity component only slightly exceeds that of the ANSI/RESNA test (1). Thus, it is very likely that the footbox alone would reduce the forces in the lateral direction below those required to pass the ANSI/RESNA test.

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A WHEELCHAIR CUSHION INSERT AND ITS EFFECT ON PELVIC PRESSURE DISTRIBUTION

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ABSTRACT

Objective: Examine a wheelchair cushion insert and its effect on pelvic pressure distribution.
Method: A quasi-experimental design was used to examine pressure distribution between the ischial tuberosities of 20 individuals who have a flexible pelvic obliquity.
Result: The data trend indicated placement of a wheelchair cushion insert under the higher ischial tuberosity resulted in increased pressure distribution between the ischial tuberosities.
Conclusion: Future research is important to increase knowledge about pressure distribution using a wheelchair cushion insert in conjunction with lateral hip guides and/or more aggressive lateral supports.

BACKROUND

Koo et al. (1), Drummond et al. (2), and Zacharkow (3,4) identified sitting with a pelvic obliquity as a postural risk factor particularly relevant to the development of pressure sores under the lower ischial tuberosity. Adaptive seating is an important part of a holistic treatment program to improve postural alignment and decrease an individual's risk for developing pressure sores. Positioning with a neutral pelvic position facilitates appropriate posture and promotes more even weight distribution between the ischial tuberosities (3,4,5).

One treatment approach for positioning individuals with a flexible pelvic obliquity is a three-point system with hip guides and laterals to correct the flexible scoliosis and therefore the pelvic obliquity (6,7). These supports are critical to provide increased spinal-pelvic alignment and pressure distribution to minimize peak pressure under a single ischial tuberosity. However, a three-point system limits an individual's ability to bend and reach.

Another treatment approach for individuals with a flexible pelvic obliquity is to build up the cushion under the lower side to re-align the pelvis (6,7). Many active individuals who use manual wheelchairs often do not use armrests or lateral supports as they feel it limits their ability to function at the wheelchair level. To provide some correction with minimal restriction, these individuals may be seated with an insert in a wheelchair cushion to increase their postural alignment and redistribute the pressure under their buttocks. This study examined a wheelchair cushion insert approach to re-align the pelvis and assess its effect on pelvic pressure distribution.

RESEARCH QUESTION

Does a wheelchair cushion insert redistribute pressure between the ischial tuberosities for individuals who have a flexible pelvic obliquity?

METHOD

Participants

A quasi-experimental design was used to examine the pelvic pressure distribution of 20 individuals who use a wheelchair as their primary means of mobility.

Instrumentation
The Xsensor Pressure Mapping System® was used to assess pelvic pressure distribution in sitting on a Jay 2 Deep Contour Cushion under three different conditions.
Procedures
A mat evaluation was performed on each individual to determine their postural seating needs and eligibility for the study. Each individual was seated with their existing back support and an appropriately sized, symmetrical Jay 2 Deep Contour Cushion, the Jay 2 Deep Contour Cushion with an insert under the lower side, and the Jay 2 Deep Contour Cushion with an insert under the higher side. On each cushion three sets of measurements were taken, to measure the average peak pressure under the right and left ischial tuberosity. For each cushion, the average difference in pressure between the right ischial tuberosity and left ischial tuberosity was computed.
The Jay 2 Deep Contour Cushion was selected as it is often used with individuals that require both positioning and good pressure relief. The cushion insert was customized to each individual's body to increase their pelvic alignment to as close to neutral as possible. It was composed of either the Jay fluid supplement pads (gel) or the Jay fluid supplement pads and the Jay obliquity build up pieces (foam).

RESULTS

The Statistical Package for the Social Sciences 8.0 for Windows (SPSS) was used to examine the data. The mean difference between the ischial tuberosities for each cushion scenario is reported in Table 1.

Table 1
Mean Difference between the Ischial Tuberosities on Each Cushion

Cushion	Mean
Cushion Without Insert	26.39
Cushion With Insert under Lower Ischial Tuberosity	30.24
Cushion With Insert under Higher Ischial Tuberosity	18.60

Note: Mean is measured in mm Hg

The SPSS paired samples t-test was used to determine if there was a significant difference between the mean between the ischial tuberosities on the cushion with the insert under the lower side and the cushion with the insert under the higher side. The two-tailed significance for the sample is 0.083. This approximates significance.

DISCUSSION

Better pressure distribution occurred when the pressure between the ischial tuberosities was decreased, as shown by the lower mean differences in Table 1. The trend of the data suggests that for individuals with a flexible pelvic obliquity, a wheelchair cushion insert under the higher ischial tuberosity redistributed pressure between the ischial tuberosities and could minimize an individuals risk for pressure sores. This data also suggests that, without lateral hip guides and aggressive lateral supports, a wheelchair cushion insert under the lower ischial tuberosity actually decreases the pressure distribution.

The SPSS paired samples t-test revealed a two-tailed significance of 0.083. Due to the small sample size, this does not achieve significance. The trend, however, approximates significance and suggests that significance could be achieved with a larger sample size.

Wheelchair cushion prescription remains highly individualized based on an individual's history and risk for pressure sores, ability to function, and goals/preferences.

Additional research in necessary to further evaluate the effectiveness of a wheelchair cushion insert in conjunction with lateral hip guides and/or more aggressive lateral support. Also, additional research with dynamic wheelchair use would provide more insight into the effectiveness of this seating intervention.

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STERNUM AND ABDOMINAL LINE
TO DESCRIBE THE THORACIC AND LUMBAR SPINE

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ABSTRACT

A sternum and abdominal line to describe the position of the thoracic and lumber spine of individuals who sit in a seating system were suggested and compared with a mean inclination angle at spine of thoracic and lumber spine using nine subjects without spinal problems. The sternum line is connected with an upper and lower sternum points and the abdominal line were done with a lower sternum point and a center point between the right and left ASIS points. Inclinations of the two lines in the frontal and sagittal plane in each subjects showed high correlation, but in the horizontal plane do not show any correlation. Two lines were shown in posture changes of individual in seating system.

BACKGROUND

To describe occupant's postures in the seating system is an important issue we have evaluated and as well their sitting abilities. Some of the issues have discussed at ISO meeting. X-ray and the Cobb' method are able to explain spinal deformities and but it isn't easy to take many X-ray pictures in a seating system because of radiation risk. It is easy to describe their posture with photographs, but is difficult to pin point anatomical postures of their body. Sonic sensor and mechanical goniometer are used to measure posture 1), it is also easy to describe their posture using stick picture. Anatomical points to show ones posture and the relations between the points and the articular joints were referred 2), but it is difficult to know spinal deformities with back support.

RESEARCH QUESTION

Indexes to describe the thoracic and lumbar spine from the front were studied. There is acromion, upper and lower sternum, ASIS and trochnter to describe a trunk. Acromion is a point of shoulder girdle and doesn't show a torso. Sternum is one of a rib cage including thoracic spine, and predicts to show thoracic spine. ASISs and greater trochanter belongs to pelvic, and connect lumbar spine. We suggest a sternum line and an abdominal line to describe position of thoracic and lumbar spine. The sternum line is a line between an upper sternum point and a lower sternum point, and the abdominal line is between a lower sternum point and a center point between right and left ASIS point. These points are easy to palpate positions from the front and small area to reduce errors in measurements.

METHODS

Measurement system: Hardware is a three dimensional digitizer (FLASH POINT, Pixsys, Inc., Colorado) consisting of three cameras, a 60cm length probe with two LED and a controller and a computer to process data.

Data: Right and left acromion, upper and lower sternum, right and left ASIS, right and left great trochanter, spinas of C7, Th2, Th4, Th6, Th8, Th10, Th12, L1, L2, L3, L4, L5 were pointed on skin by the probe. Eight front points, twelve back points and a probe in each posture got three ground points. These three dimensional position data according to the spatial reference plane were gotten. Spatial reference system was an origin that was a point under the sacral spine on the platform, x-axis and the positive direction that was from the origin to right in the frontal plane, a y-axis and the positive that was to forward in the sagittal plane, and a z-axis and the positive that was to upper in the horizontal plane.

Data process: Inclinations in sternum line were calculated from positions of an upper and lower sternum in each plane. In abdominal line, a center of right and left ASIS was calculated, and after that inclinations were done from a lower sternum and a center point of it. First in spine, positions of two adjacent anatomical makers in each thoracic and lumbar spine were calculated angles, after that, inclinations were figured out from the average angles exception a maximum and minimum in each thoracic and lumbar spine. Inclinations between a sternum and abdominal line and a thoracic and lumbar spine were compared and processed statistically.

Subjects

Ten subjects without spinal problem were participated in the research study (age: 23-38 years, height: 168-184 cm). Subjects sat on 41.5cm height platform with a 6cm form cushion and took postures including straight, light and hard left and right inclination, light and hard left and right scoliosis, light and hard lodosis.

RESULTS

Anatomical points in one posture when the subject leaned his body to the left side were shown in the frontal and sagittal plane (Fig.1). Inclinations of the sternum and abdominal line in the subject's all postures were directly proportional to it of the thoracic and lumbar spine in the frontal and sagittal plane, and not in the horizontal plane. Inclinations in the frontal were linear through origin, but in the sagittal plane did not pass the origin (Fig.2). These inclinations in the frontal and sagittal plane were shown closely 1(Table.1).

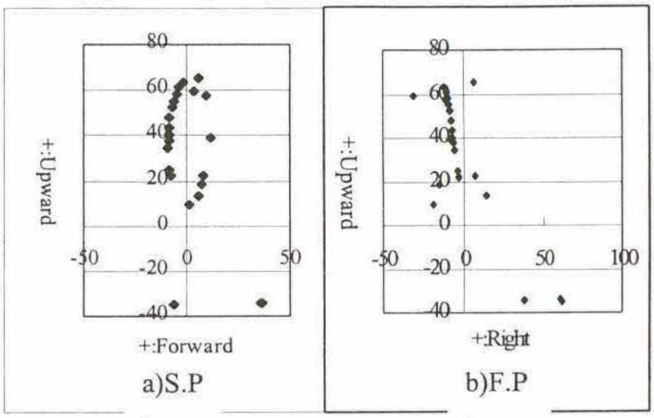

Fig.1. anatomical points in one posture in the sagittal plane(S.P.) and frontal plane(F.P.).

DISCUSSION

The accuracy of the digitizer in user's manual is 0.05mm. Length and the SD of sternum between upper and lower sternum, between right and left ASIS and between right and left great trachanters was 17.8, 24.0 and 34.8cm and S.D.0.7, 0.9 and 1.1cm, for a subject. The error is corresponding to the area of anatomical landmarks pointed out by the probe.

According to the results, inclinations of a sternum and abdominal line had correlation with the inclinations of the thoracic and lumbar spines in the sagittal and frontal view in each person. Information of line is smaller than it of curve in spine. Ordinary, Centrum of body of vertebra is a point of kinesiology in spine, and have difference in position with process of spine. Configuration of trunk has difference with each body. Inclination in the frontal plane is possible to be comparing with other person's. But if his spine has a rotation, it is very difficult to compare it. A sternum and abdominal line was shown one index to describe his torso in a seating system.

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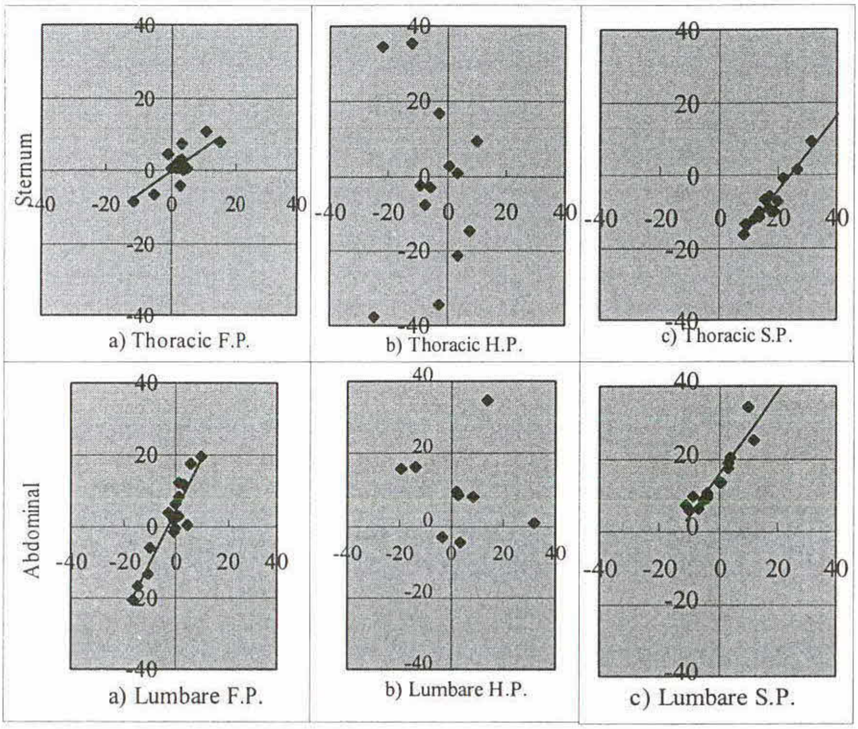

Fig.2 Relation of inclinations between a sternum and abdominal line and the thoracic and lumbar spine. The longitudinal axis shows inclination in the sternum and abdominal line.

Table 1. Correlations and Inclinations

Case	correl/th/fr	incl/th/fr	correl/th/sg	incl/th/sg	correl/lm/fr	incl/lm/fr	correl/lm/sg	incl/lm/sg
1	0.91	0.88	0.99	0.83	0.78	0.91	0.64	0.87
2	0.94	1.18	0.88	1.04	0.82	0.91	0.94	1.12
3	0.88	0.95	0.98	0.95	0.91	0.89	0.76	0.68
4	0.94	0.88	0.97	0.97	0.75	1.26	0.78	1.14
5	0.99	1.02	0.96	0.82	0.69	0.79	0.91	0.79
6	0.94	1.16	0.90	1.08	0.92	1.16	0.93	1.24
7	0.87	0.84	0.73	0.67	0.94	1.05	0.96	1.08
8	0.87	0.85	0.71	0.63	0.94	1.05	0.97	1.10
9	0.82	0.64	0.97	1.03	0.94	1.45	0.96	1.13
10	0.87	0.91	0.88	0.78	0.91	1.00	0.93	0.97
average	0.90	0.93	0.90	0.88	0.86	1.05	0.88	1.01

*correl:correlation, incl:inclination, th:thoracic spine, lm:lumbar spine, fr: frontal plane, sg: sagittal plane.

3D COMPUTER MODELLING IN WHEELCHAIR DESIGN: A CASE STUDY

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ABSTRACT

Computer modelling has not been evaluated for its usefulness in optimising the stability of powered wheelchairs. A lumped mass model of a prototype powered wheelchair was constructed using a commercially available simulation package. The model was used to predict the gain in lateral stability resulting from design changes. Although the model was found to be useful, further research is required to improve the representation of the mechanical properties of tires.

BACKGROUND

Most powered wheelchair accidents are design-related; 42% of accidents are due to component failures, and 30% are due to tips and falls resulting from wheelchair/rider instability [1]. Therefore, a greater understanding of the effects of wheelchair design on stability will likely reduce accidents.

Static stability of wheelchairs has been studied extensively and is well-documented [2]. However, static stability is only one factor that contributes to the dynamic behaviour of a wheelchair [3]. Dynamic stability has been studied using standardised tests and an ordinal scale [3,4]. This experimental method is insensitive to small design changes and can only be used to analyse existing prototypes [4].

Dynamic computer models have been used because they have the potential to accelerate the prototyping process and to simulate scenarios too difficult to test experimentally. Models that analyse wheelchair instability over a variety of terrain have been generally derived from symbolic equations of lumped mass systems [5,6]. But these models have never been critically analysed for their usefulness in wheelchair design.

RESEARCH QUESTION

A tool needs to be developed that is capable of predicting how design changes impact the static and dynamic stability of a wheelchair. The research question of this paper is whether a current commercially available lumped mass simulation model is useful in designing stable wheelchairs.

METHOD

A 3D lumped mass model of the Rocket ™ was created within *Knowledge Revolution's Working Model 3D* v.4.0 (WM3D): a Windows-based dynamic simulation that analyses Newtonian mechanics. The Rocket is a mid-wheel drive prototype wheelchair. The two centrally driven wheels are forced downwards by a pre-compressed spring aligned within a telescoping shaft. Four casters are attached directly to the corners of the wheelchair frame (see Figure 1). The model was used to analyse designs that had the potential to increase the lateral stability of the wheelchair without sacrificing manoeuvrability.

The model of the wheelchair (including a 100 kg rider) was developed from 43 rigid bodies (i.e., ellipsoids and cylinders) attached via constraints (i.e., revolute joints, springs, and motors). The model was refined using the following measurements from the Rocket: the centre of gravity (3D); the ground reaction forces; and the displacement of the wheels, frame, and occupant as the wheelchair passed over a bump. The accuracy was determined by comparing the static stability angles of the model with those from the Rocket measured on a tilting platform. The forward, rearward and lateral static stability angles were defined as the respective angles through which the wheelchair rotated before the force under the uphill casters became zero *.

The model was used to predict the lateral stability gained with three different design alterations. First, the width was increased by 10 cm. Second, the motion of the central suspension system was limited when on sloped terrain. Third, the centre of gravity was lowered by adding a 10kg weight under both the front and rear batteries.

RESULTS

Figure 1: Model in *Knowledge Revolution's Working Model 3D*

The resulting model is illustrated in Figure 1. Figure 2 compares the predicted static stability angles with the acutal measured values. The predicted angles were within 2.5° of the measured angles.

The lateral stability predictions from the model are illustrated in Figure 3. The increase in width, suspension limit, and added weights resulted in a 24%, 74% and 15% improvement in lateral static stability, respectively.

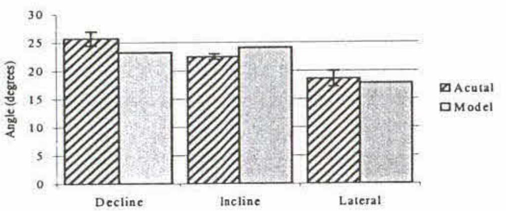

Figure 2. Model accuracy: comparison of the predicted static stability angles with the measured angles. All casters trailing backwards and unlocked.

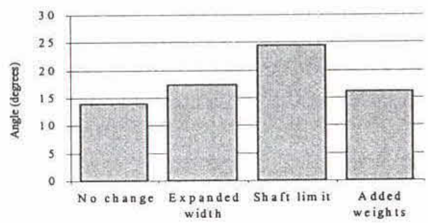

Figure 3. Model predictions: comparison between four designs in terms of their lateral static stability angles. All casters in the least stable configuration and unlocked.

DISCUSSION

WM3D has a simple user interface and consequently is easy to learn. Simulations are viewed via keyframe animation and the output is quantified with numbers, graphs or vectors. Although spatial models can be built rapidly, their refinement was found to be time consuming due to the inability of WM3D to accurately model tires and complex friction.

Wheels act as the interface between the wheelchair and road surfaces and thus are critical in vehicle dynamics. The wheels were not modelled accurately since all bodies within WM3D are rigid. Only the vertical wheel stiffness of the wheels was incorporated in the model; simple analytical tire models adopted from the automotive industry overburdened the model. Furthermore, the wheels were modelled with spheres since these are the only analytically defined bodies within WM3D. WM3D has recently developed a tire add-on that is currently being critically analysed.

The wheelchair is statically indeterminate since more than three wheels are in contact with the ground. The indeterminacy caused the model to respond sensitively and sometimes unpredictably. Therefore, the model refinement required more precision and effort than expected. The actual stability angles measured from the Rocket also varied by +/- 1.6° because of this physical indeterminacy.

The friction in the telescoping shaft was particularly difficult to model because the coefficient of friction changed along that shaft. Furthermore, since friction is proportional to the normal force, the friction force was calculated using data from the previous frame; this resulted in small oscillations in the wheelchair's predicted performance.

Overall, the preliminary results from the simulation software are promising. The model was able to predict which design option should be invested further. However, further research is required to develop an accurate tire model and alternative methods of incorporating friction before the full potential from the software can be achieved.

The model is currently being used to analyse the effect of the three alternative designs on the Rocket's dynamic stability.

* The static stability angles were not necessarily the tipping angles of the wheelchair: they were the angles at which two (out of six) wheels were no longer in contact with the ground.

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ACKNOWLEDGEMENTS

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LOW COST SEAT CUSHION DESIGNS: SOREBUTTS 1996 TO 1999

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ABSTRACT

In developing countries, pressure ulcers are the number one cause of death among people with disabilities. Currently, there are very few low cost seat cushion designs. The SoreButts cushion competition was started in 1996 to encourage the creation of inexpensive seat cushion designs. The entries have utilized air chambers, foam, compressible fill, granular fill, elastic sling, and firm contours to provide pressure-relief, comfort and stability.

BACKGROUND

The use of wheelchair cushions to help prevent the development of pressure ulcers is well established and a variety of commercial wheelchair seat cushions are available in the United States and other wealthier nations. One type of seat cushion cannot meet the needs of all wheelchair users; therefore, different technologies and designs are essential. These seat cushions are designed to provide a comfortable, pressure-relieving area that is durable, easy to clean, easy to maintain, and lightweight.

STATEMENT OF THE PROBLEM

In developing countries, pressure ulcers are the number one cause of death among people with disabilities. The resources to purchase or manufacture state-of-the-art cushions are not available. The majority of commercial seat cushions cannot be produced in these areas because they require materials or manufacturing techniques that are not readily available. Currently, there are very few low cost seat cushion designs for people with disabilities.

DEVELOPMENT

In order to stimulate designs for low cost, locally-produced wheelchair cushions for the prevention of pressure ulcers, an international cushion design competition was started in 1996 by the RESNA Special Interest Group on International Appropriate Technology (SIG 17) (1). The "SoreButts" cushion competitions were held in conjunction with the annual RESNA Conferences. Designs were required to be original; therefore, commercially available cushions and previously submitted designs were not eligible for the competition. Contestants completed an entry form and submitted it with their cushion. The entry form was used to obtain more detailed information about the cushion, including: materials required, quantities of each material, source of each material, estimated cost in U.S. dollars, list of equipment/tools used to construct the cushion, step-by-step, detailed instructions on how the cushion was constructed, total construction time, weight of the cushion, maintenance (cleaning and care), and special features (e.g., adaptability of size and shape).

LOW COST CUSHION DESIGNS

Twenty-two different cushion designs have been generated through the SoreButts cushion competition: the winner from 1996, 4 entries from 1997, 9 from 1998 (2), and 8 from 1999. The cushions have been classified into six different categories: air chamber, foam, compressible fill, granular fill, elastic sling, and firm contour. Some cushions utilized multiple design characteristics.

Air Chamber

Several cushions have been designed using an air chamber for pressure relief. The winning cushion in 1996 consisted of dozens of individual air sacks formed by tying a series of knots in semi-inflated bicycle inner tubes and arranging them into a cohesive seat. Variations on this concept included: 1) arranging bicycle inner tubes in patterns designed to minimize pressure on areas prone to skin breakdown, 2) weaving the inflated inner tubes with strips of cloth, or 3) using a single, doughnut-shaped inner tube to cover the seat. Designers have suggested varying the amount of inflation of the tubes, as well as filling the inner tubes with water or a cushioning material instead of air.

Foam

A variety of foam types are available in many areas as industrial refuse or a cheap and readily available commercial product. Packaging foam (in sheets or as "peanuts") has been used in some of the cushion designs, as well as a granular foam product (beanbag filling). Various open-cell foams specifically designed for cushioning (e.g., bedding, upholstery) are often cheaply available, sometimes as remnants. Thin layers of foam sheet are often used on top of other cushioning elements. Loose chunks or grains of foam are packaged in compressible-fill cushions or granular-fill cushions. The 1999 winner used a thick block of open-cell foam scored with a sharp knife in a checkerboard pattern in order to reduce shear stress on the wheelchair rider's skin.

Compressible Fill

Loose material such as scraps of foam, industrial cotton by-products, and various organic materials such as hay or coir (a springy fibrous material from the inedible outer husk of a coconut) have been contained in various fabrics to form a cushion. The material has been placed in a single large chamber, or quilted in smaller chambers. Some designs have incorporated specially shaped chambers to divert pressure from areas prone to skin breakdown.

Granular Fill

Various granular materials have been used to distribute pressure across the seat. Some of the granular fillings have been hard materials, such as dried pinto beans, which provide pressure relief by freely moving within the cushion cover to conform to the user and distribute pressure. Other granular fillings, like popped popcorn, mung bean hulls, or the buckwheat hulls of the 1998 winning entry, are somewhat compressible.

Elastic Sling

A 1997 entry consisted of strips of elastic material (inner tube rubber) woven and stretched across a rectangular frame to form a resilient sling.

Firm Contour

Cushions provide pressure relief by forming a surface that closely contours to the seated wheelchair rider, distributing pressure over the entire surface. While this contour can be accomplished passively by using materials that move or compress, another strategy for providing pressure relief is to use firmer materials to create a shaped surface that retains its contour. This contour has been accomplished by rigid materials such as wood or paper-mache with layers of resilient material such as foam on top, or by carving into a semi-resilient material. Coconut coir which has been processed into sheets of dense, resilient material is cheaply available as an industrial product in some areas and has been carved to provide a contoured shape.

EVALUATION

All cushion entries were formally judged at the RESNA Annual Conferences. The cushions were judged by teams of experts that included rehabilitation engineers, clinicians, designers, and consumers. The cushions were evaluated and rated on comfort, stability, pressure distribution characteristics, intuitive use, catastrophic collapse, wash-ability, breathe-ability, durability, weight/portability, cost of materials, and labor time. An anatomical test fixture ("GelButt") (3) was used to load each of the cushions consistently to make repeatable and comparable pressure measurements using an FSA (Force Sensing Array) Pressure Measurement System (Vista Medical).

Over the years, many innovative and successful designs have been entered into the competition. The winning designs for each year of the competition were:

- Bicycle inner tubes tied into individual semi-inflated segments, arranged in rectangular pattern 3 layers deep (entry 96; air chamber);
- Foam rubber sheet over contoured coconut coir (scooped out under ischials and tailbone), rubberized cloth cover (entry 97-03; foam);
- Buckwheat hulls in a bag sewn from a T-shirt (entry 98-03; granular fill); and
- Foam block scored in checkerboard pattern to minimize shear, cavity under tailbone filled with coconut fibers, linen cover with zipper (entry 99-07; foam).

DISCUSSION

The SoreButts International Wheelchair Cushion Design Competition has served to help in the development of new designs for low cost seat cushions. Continuation of the competition will hopefully help improve the availability of cushions in developing countries and impoverished areas of the world.

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WEB SITE ON WHEELCHAIR PROJECTS IN DEVELOPING COUNTRIES

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ABSTRACT

There are an estimated 20 million people with disabilities in developing countries who need a wheelchair. Currently, there is a lack of compiled information on the different wheelchair projects conducted around the world. The objectives of this project are to gather information about past, current and future projects from organizations that provide wheelchairs to people in developing countries, and to develop a Web site to make this information readily available. Providing a centralized source of information will help to identify the needs of specific geographic locations and will assist organizations in coordinating projects to prevent conflicting efforts.

BACKGROUND

There are an estimated 20 million people with disabilities in developing countries who need a wheelchair, and less than 1% own or have access to one (1). Because of this tremendous need, numerous organizations are currently working to provide wheelchairs and other assistive mobility devices to people throughout the world. These organizations differ significantly in their approaches and philosophies to meeting this basic need of people with mobility limitations.

Immediate Assistance

Similar to the approach of the American Red Cross (2), some organizations provide immediate assistance by distributing wheelchairs manufactured for wealthier nations to people in other countries. The majority of these wheelchairs are donated and refurbished in the U.S., and then delivered free of charge to people in need. Hope Haven International Ministries (Rock Valley, Iowa) (3), Wheels for Humanity (North Hollywood, California) (4), and Wheels for the World (Agoura Hills, California) (5) are just three organizations among many that distribute refurbished chairs to people with disabilities in developing countries. This approach provides an immediate, but often temporary solution. The parts, materials, and construction methods for performing wheelchair repairs and regular maintenance are not always readily available in many of these areas.

Sustainable Provisions

Heifer Project International is an example of an organization with a completely different approach. This organization works to build sustainable communities that have the knowledge and training to provide food for themselves (6). Motivation (Bristol, U.K.) (7) and Whirlwind Wheelchair International (San Francisco, California) (1) are two organizations that work in developing countries to establish sustainable production and distribution of appropriate wheelchairs made from locally available materials. This approach addresses the long term needs of the community, but requires a significant amount of time to develop these wheelchair building shops.

Complementary vs. Conflicting Efforts

By applying these two different approaches at the appropriate time, they can serve to meet both the immediate and long term need for wheelchairs in developing countries. However, there have been instances where refurbished wheelchairs were distributed to a community in which a wheelchair building shop was under development. Although the refurbished chairs are typically heavy depot-type wheelchairs that are not designed for use in the outdoor environment, they are given away freely and thus can destroy shops that are trying to sell low-cost, appropriate wheelchairs.

OBJECTIVE

How can the different organizations coordinate their projects to better meet the needs of the developing communities, with the goal of creating a long term, sustainable solution? Currently, there is a lack of compiled information on the different wheelchair projects, so organizations often do not know what has already been accomplished in a particular region or what is being planned for the near future. The objectives of this project are to gather information about past, current and future projects from organizations that provide wheelchairs to people in developing countries, and to develop a "Tools for Life" Web site to make this information readily available.

METHOD OR APPROACH

At the 1999 Annual RESNA Conference held in Long Beach, California, this project was presented as a topic for a roundtable discussion, coordinated by the Special Interest Group on International Appropriate Technology (SIG-17). Representatives from Hope Haven International Ministries, VIVCO Assistive Technology Services, Wheels for Humanity, and Whirlwind Wheelchair International attended and provided valuable input. The discussion participants confirmed the need for a centralized source of information on wheelchair projects in developing countries. The discussion group reviewed a draft list of items and brainstormed on additional information to be gathered from each organization.

RESULTS

The following information was identified as important and will be gathered from each organization using a mailed or e-mailed survey. In addition, the group also concluded that it would be desirable to search for specific projects based upon geographic location.

Contact Info.
- Name of organization
- Address
- Phone, Fax, Email
- Web site
- Contact persons
- Other offices

Affiliates
- Partners: local, gov't, manufacturer, disability organization
- Links to other Web sites

Organization Info.
- Year founded
- Mission statement
- Goal & objectives
- Expertise & skills
- Languages
- Developing country / wealthier nation
- Funding source
- Annual budget
- Number of assistive technologies produced and/or distributed

Type of Organization
- Not / for profit
- Medical / clinical
- Type: refurbishing, distributing, design, manufacturing, service, advocacy
- Assistive technology: manual wheelchairs, powered wheelchairs, other mobility, augmentative & alternative communication, prosthetics & orthotics, sensory loss

Specific Project Info.
- Start date
- End date
- Country / region
- Project description
- Contact person
- Project team needs (summer interns, time involved, training, funding)
- Project resource needs
- Languages

DISCUSSION

This SIG-17 project is in its initial stages of development. Survey templates will be drafted and circulated to the organizations that participated in the roundtable discussion in June of 1999. The survey templates will be revised based upon feedback received and then sent out in the beginning of 2000 to any organization identified that provides wheelchairs or other wheeled mobility devices to people in developing countries or impoverished areas of wealthier nations. The information collected from each organization will be compiled and made available on the Internet through the Tools for Life Web site which will be part of the Beneficial Designs' Web site at <www.beneficialdesigns.com>. Feedback on the Web site design and information provided will be sought from RESNA conference attendees in June of 2000.

The goals of the informational "Tools for Life" Web site are to:

1. Identify the needs of specific geographic locations and communities;
2. Facilitate collaboration between the various organizations to prevent conflicting efforts;
3. Present the needs (funding, volunteers, etc.) of specific projects to assist organizations with obtaining resources necessary for project completion; and
4. Assist therapists, engineers, volunteers, and others in finding opportunities to work in developing countries to provide mobility technologies.

The long term goal is to better meet the needs of people with disabilities in developing countries through the provision of appropriate technology.

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DESIGN OF AN IMPROVED HOCKEY SLED

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ABSTRACT

Sled hockey equipment lacks sufficient safety features for the lower extremities, adequate adjustability, and is often uncomfortable for the duration of a game. Based upon input from athletes throughout the country, including players on the U.S. Sled Hockey Team, a new design is being developed to address these areas of needed improvement. A protective shell has been designed to protect the lower leg, ankle, and foot from impact injuries. The sled allows for a wide range of blade placement and overall length to accommodate performance adjustments for an individual player or for shared use by different players such as found in club use. Integrated into the sled is additional support for the knees, which will improve the athlete's balance and control. Improved safety and comfort will allow athletes to play with greater confidence and higher performance.

BACKGROUND

Sled hockey began in Norway during the 1970's. The original sleds were heavy and uncomfortable, but over time the sleds have evolved into sleek and refined machines. Sled hockey was first introduced into the United States about 10 years ago, and its popularity has grown across the country. There are currently 12 teams, and at least 5 teams in development. In 1998, sled hockey was successfully debuted as a paralympic sport in Nagano, Japan. The U.S. team competed in the event.

Sled hockey is hockey. All of the rules of hockey apply, with some modifications due to the equipment used. A sled replaces the ice skates, and two shortened hockey sticks with picks on the ends serve to maneuver the athlete as well as to handle the puck (Figure 1). The rules of the game can be found in the "International Paralympic Committee Ice Sledge [Sled] Hockey Rule Book," (1). The book regulates sled design as well as the rules of the game. Some of the more interesting regulations include sled under-body clearance (approx. 7.5 cm) and maximum tube diameter (3.0 cm). The design restrictions for the sled are intended to protect the players, however they may ultimately limit design innovation.

Figure 1. Kingston Kestrels player. (2)

STATEMENT OF PROBLEM

The purpose of this project is to improve the existing sled technology. Safety of the sleds will be improved by better protecting the lower extremities. Increasing the adjustability of the sleds will allow US team members to optimize their sled configuration as well as to support the shared use of sleds among club teams members. Including an optional knee support bar will make improvements in comfort and balance. It is important that any design improvements maintain the lightweight, durable, fast, and maneuverable characteristics found on current sled designs.

RATIONALE

Design improvement ideas have been gathered from hockey players across the country. An initial email survey was circulated through the National Team. An Internet chat session was held with players from the National Team as well as players on various club teams that allowed a geographically diverse focus group to be held. Nine players from across the country participated. Follow-up phone interviews were conducted with the players as well as with individuals who manufacture sleds.

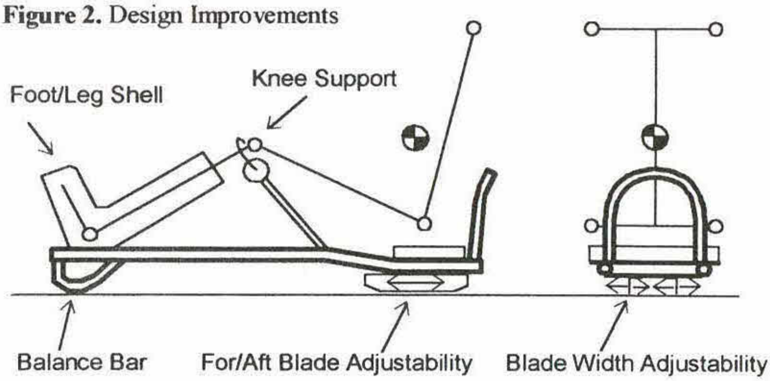
Several conclusions were reached about improvements to the equipment. The current sleds do not provide adequate protection for the lower extremities. Most sleds incorporate little more than a small protective bar providing only partial protection and support for the feet. It is very easy for the feet to be bent back during head on impacts, which can cause broken ankles.

Players expressed their dissatisfaction with the comfort and adjustability of their sleds. In an email survey, one player rated the comfort of his sled as one on a scale from one to ten (ten being high). Other player responses showed similar dissatisfaction. Many of the players were either too tall or too short for their sleds. A highly adjustable sled lends itself to greater comfort by allowing the user to improve the fit of their sled. Proper fitting of the sled also improves a player's performance. An adjustable sled design benefits clubs and hockey leagues, by allowing multiple users to use the same sled. . The use of a knee support bar increases comfort and allows users to better regain their balance after reaching or leaning forward during play.

DESIGN

A prototype protective shell system for the lower legs has been designed (Figure 2). The shell system protects the shins and reinforces the ankles to prevent injury. The shell system consists of two shells, one for each foot. The shells resemble a lightweight, knee-high boot. The boot is open on the topside, allowing the foot to be easily put in. Once the foot is in the boot, a strap is secured across the top. The use of two boots allows single amputees to remove one boot to save weight. The boots clip onto the front end of the sled frame, allowing players to get in and out of the sled easily. A molded thermoplastic is used in the construction of the boots.

Figure 2. Design Improvements



Unlike foot skates, hockey sleds have two blades spaced laterally apart to allow for balance when sitting upright. When first learning the sport, players typically start out with the blades 15 cm (6 inches) apart for stability and then move them closer to about 10 cm (4 inches) as they get better, which results in better handling. Adjustment of the overall fore/aft position of the blade allows players to position their center of mass in the optimal location over the blades. When first learning the sport, players typically start with the blades further back and move them forward as their skill improves. The blades adjust along sliders, allowing more precise placement than can be achieved using independent predrilled holes, which are found on some sled designs. The overall length of the sled has been made adjustable by incorporating telescoping tubing to connect the front and rear ends of the sled.

Including an optional knee support bar improves comfort and balance. This support allows users to secure their knees in an elevated position, which has been shown to improve performance in mono-ski designs and road racing wheelchairs. Isolating movement in the knees by attaching them individually to a rigid bar improves overall control of the sled by adding rotational and lateral support of the pelvis. The knee support is easily removed/attached, but when used, it attaches to the frame under the front of the seat and angles forward with the upper legs. The seat is mounted directly above the blades, as low as possible to the ice to optimize sled handling. The seat mount is compatible with most existing seat frames, making it easy to replace the seat with a custom bucket seat for players who need more trunk support or want a more custom fit. The seat accommodates a variety of active cushions.

DEVELOPMENT

Several aspects of the design are still under development. A prototype device has been developed and shows promise. The lateral blade offset adjustability allows players to more finely optimize maneuverability by trading upright balance for increased turning and checking performance. Players are anxious to experiment with designs offering better protection the lower legs during impacts.

EVALUATION

So far the prototypes are promising. The United States Sled Hockey team athletes will test the design during practice sessions to generate feedback. A user survey will be developed to evaluate the key characteristics of the sled including stability, handling, and durability. Feedback will also be gained from assessment by Beneficial Designs, Inc and a Santa Clara University advisor.

DISCUSSION

Future work on the project involves building, testing and revising the design. The design team is confident that the sled design improvements will increase performance, thereby giving the United States Sled Hockey Team an edge in the next paralympic games. The improved design will also be useful to clubs and youth leagues as a high performance sled that can be adapted for use by different players.

ACKNOWLEDGMENTS

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BACKPACK ASSISTIVE DEVICE FOR WHEELCHAIR USERS

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ABSTRACT

For the 1.5 million wheelchair users in this country[1], current wheelchair technology does not provide much practical storage capability. For those users, carrying bags/backpacks is a cumbersome activity. We have conceived of, designed and built a working prototype of an alternative storage device that provides easy access to the items that wheelchair users can carry with very little effort required by the user to operate. Moreover, our device would keep interference with the intrinsic design of most wheelchairs to a minimum, it would be easy to install, would require very low maintenance and have a low cost.

BACKGROUND

Until recently (1980's-present), there has been very little improvement in wheelchair accessories. The market has made a limited amount of devices to help assist wheelchair users in having access to their bags/backpacks. Currently, there are three commonly used means for wheelchair users to carry their personal items. One method is a side-mounted bag that attaches over the side of the wheelchair. It is not cosmetically pleasing and it makes the wheelchair wider, reducing the ability for the wheelchair to fit through doors (Figure 1). Along with that, the device is not universally compatible with all wheelchairs, and can only help those select users with the appropriate wheelchair design.

The market has also made custom-made bags for wheelchair backs. (Figure 2) However, this method requires the user to have considerable upper body strength and range of motion since to access the bag the user must turn his/her body around more than 90 degrees to gain access to their belongings. The third method consists of simply carrying their bags/backpacks on their laps. This method is somewhat unsafe for the user and requires the user to hold on to the bag while moving.

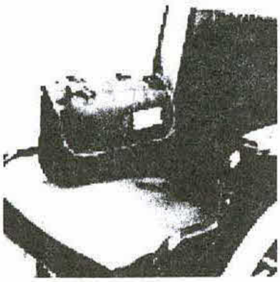

Figure 1

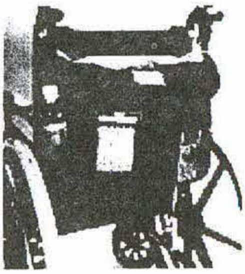

Figure 2

STATEMENT OF THE PROBLEM

Currently available methods for wheelchair users to carry personal items are not efficient. Moreover, they put the user in an awkward position of either hyperextending themselves while reaching for their bag, or risk dropping their bag while carrying it on their lap.

[1] From the 1990 Census Bureau (http://www.census.gov/hhes/www/disable/census/tables/tab3us.html)

BACKPACK ASSISTIVE DEVICE

RATIONALE

We believe we can provide wheelchair users with an alternative storage device. This device will perform the operation of stowing and obtaining a backpack for a wheelchair user. The device will be cosmetically appealing, along with having the ability for easy detachment when not in use. At the same time, this alternative device keeps interference with the intrinsic design of most wheelchairs to a minimum, requires very low maintenance and has a low cost.

DESIGN

Our device is mainly comprised of the following parts. Two clamps used as mounting devices. These clamps would be attached to each side of the wheelchair (Figure 3a) and will serve as points of attachment for our device. There is also a horizontal bar that has two welded hooks where a backpack could be placed (Figure 3b). This bar is attached to a JACO bracket (Figure 3c) by means of a metal pin. The JACO bracket is bolted on to either clamp depending whether the user is left or right handed. Finally a latch is attached to the other clamp and it is used to lock the device in place.

The way the device will operate is quite simple. When the user wants access to their bag/backpack, they will activate the latch releasing the bar with the bag on it. Since the JAECO bracket is mounted at an angle, the bar will swing around due to gravity. The bar would stop about 40 degrees before reaching the user and the user will bring the bar close to him/her manually (Figure 3d). As the bar gets close to the user, the JACO bracket changes the positioning angle and prevents the bars range of motion from going back, while the user is getting his/her belongings. When the user is ready to put their bag back into the closed position they will have to push the bar away from them until the bar locks into place.

EVALUATION

After testing our prototype we have observed that the device appears to have improved the conditions to carry and to access personal belongings just as we had intended. However, we believe that the device can still be improved in two ways. The first is to use a better actuation mechanism so the user will not have to manually lock the device into place. One of our options at this point is to add electromechanical parts to accomplish this purpose. The second area in which the device can be improved is to make the transition angle of the JACO bracket smoother. We believe adding a spring to the bracket can solve this.

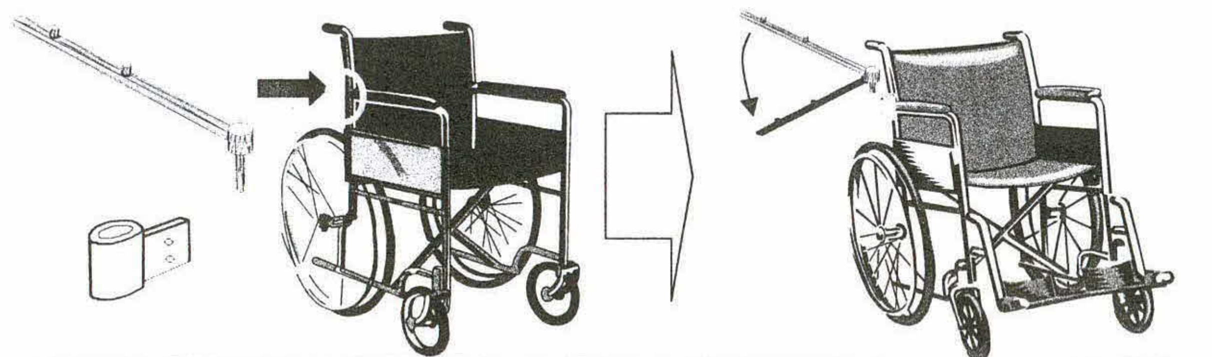

Figure 3: a) Location of device on wheelchair (middle); b) Main Arm (top left); c) JAECO bracket (bottom left); d) Device configuration and motion on wheelchair (right).

BACKPACK ASSISTIVE DEVICE

DISCUSSION

The backpack assist device does have many benefits to most wheelchair users. We have seen on campus how most wheelchair users carry their backpacks, and how users around the city carry their bags. Most of these users could benefit from this device, giving them the ability to access their backpacks/bags with greater ease. At this point, the targeted users of this device must have good range of motion in their arms and a sufficient amount of strength to operate this device. The strength requirements, however, depend on the kinds of loads that the user will be carrying. A young child (5-10) could easily use the device to carry their schoolbooks, but the child may have a problem using the device to carry a load of over 20 pounds.

The most important aspect to the user is that their wheelchair is compliant with the device. Currently, the device can be placed on any wheelchair that has a vertical bar that is placed at the rear of the wheelchair (refer to figure 3a). However, users with square bars, or sport wheelchairs (that usually do not have vertical bars on the rear) will not be able to use this device.

The device is compliant with any kind of book bag, knapsack, or bag. The user would be able to hang their backpack using the two hooks, use a shoulder-carry bag and hang it from one, or even use two plastic shopping bags and hang each from each hook. This feature gives it universal use, especially to users using backpacks, going food shopping, or just going into any situation in which they may need to carry any supplies.

The device is safe to operate and it is inconspicuous providing for excellent cosmeses. The devices' durability is an attractive characteristic. Since there is a minimal amount of moving parts, the durability of the device should easily last many years (more than the wheelchair). The device is able to carry a load of up to 30 pounds and can be sold for about $50 or $60.

CONCLUSION

The backpack assist device could help many thousands of wheelchair users who struggle with reaching their bags. Overall, the final device will be cheap to the user ($50 after labor and materials), and unobtrusive to their wheelchair. We expect it to be practical, and successfully employed if offered to wheelchair users.

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ACKNOWLEDGEMENTS

The realization of this design was possible by the help provided by Dr. Adrian Polliack and Mr. Vicente Vargas at the Rancho Rehabilitation Engineering Program at Rancho Los Amigos National Rehabilitation Center. They provided critical advice and some of the materials used in the construction of the device.

HAND AND WRIST EXTENSION EXERCISE DEVICE

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ABSTRACT

Wrist injuries are common. These injuries may be due in part to an imbalance between the strength of the flexor and extensor muscles of the hand and wrist. One method to reduce the likelihood of wrist injuries may be strengthening the extensor muscles. Products are available for exercising the extension muscles of the hand and wrist but are either not comprehensive for both the hand and wrist or are not simple ambidextrous interfaces. A hand and wrist exercise device was designed to allow strengthening and conditioning the extensor muscles of the hand and wrist in one motion. The exerciser serves as a preventative tool against wrist injuries.

BACKGROUND

Muscle imbalance across a joint has been shown to be associated with joint injury (1). Function of the hand is primarily in flexion during everyday activities. Overuse of the hand may lead to an abnormal imbalance between the flexor and extensor muscles. Manual wheelchair propulsion is a repetitive activity that requires use the flexor muscles of the hand and wrist. Strengthening the extensor muscles of the hand and wrist may decrease susceptibility to wrist injury.

Products are available for exercising the extension muscles of the hand and wrist. The Knuckle Bender Splint (Rolan) is a product designed to exercise the fingers in extension. It uses rubber band resistance between the palm of the hand and the back of the four fingers. The Hand Gym (Maddak, Inc.) also exercises the hand in extension using rubber band resistance. This product allows different finger joints to be exercised independently. The Flextend (Balance Systems, Inc) is a product that allows both the hand and wrist to be exercised simultaneously. The Flextend consists of a glove with an elastic band that attaches from the ends of each finger to a strap that is then secured around the biceps. The elastic bands pull the wrist and fingers into a flexed position.

Most of the products on the market focus on exercising either the hand or the wrist, but not both. Most products also lack the ability to adjust the applied resistance and are not ambidextrous. A need exists for a lightweight, variable-force hand and wrist exercise device that incorporates both finger extension and wrist extension.

STATEMENT OF THE PROBLEM

Products are available for exercising the extension muscles of the hand and wrist but are either not comprehensive for both the hand and wrist or are not simple ambidextrous interfaces. A need exists for a simple, effective exercise device for the extension of the hand and wrist.

DESIGN AND DEVELOPMENT

Design Requirements

To keep the devise simple and natural to use, exercising the hand and wrist should be done in one fluid motion. One fluid motion allows the user to exercise efficiently thus reduce the amount of time needed to effectively strengthen the extensor muscles (2). The motion begins with the hand

and fingers in a natural flexion position and ends with the hand extended about the wrist and the fingers fully extended. The resistance of the device should be adjustable to allow users to strengthen as well as condition the extension muscles.

Concept Generation

Several different concepts were generated and evaluated for feasibility. Design attributes most heavily weighted during selection were the ability for a single continuous exercise motion, variable resistance mechanism, ambidextrous, comfortable, and intuitive to use. The design concept chosen incorporated all of these attributes (Figure 1). The design consists of a single device that can be used to exercise both the right and left hands. The hand is placed through the arm cuff, under the wrist lever and rests against the finger lever. The wrist lever is hinged about the arm cuff. Resistance is applied by a compression spring in the wrist resistance mechanism. The finger lever is hinged about the wrist lever, in order to provide independent motion of the hand and wrist. The finger resistance mechanism consists of a torsion spring with an adjustable pre-load. This design allows exercise of wrist extension, hand extension, or both using independent resistance mechanisms.

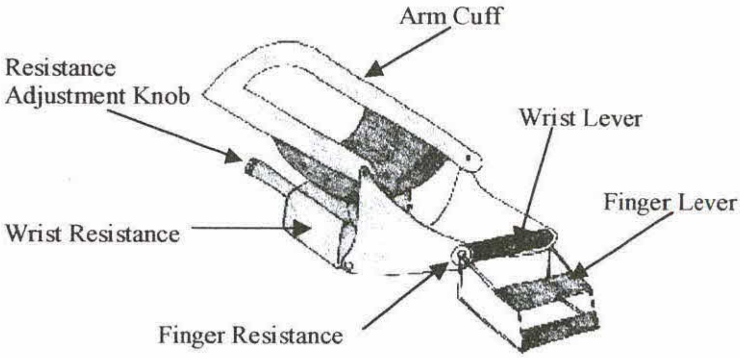

Figure 1. Preliminary Extension Exerciser Design

Functional Prototype

A functional prototype was developed and evaluated (Figures 2, 3). The arm cuff of the device consists of a molded, rigid plastic with foam applied to the areas where it contacts the arm. The arm cuff stabilizes the exercise device onto the arm during exercise and serves as a mounting location for the wrist pivot location. The wrist pivot allows for full range of motion of the wrist, from fully flexed to fully extended. The wrist resistance mechanism is mounted to a stationary point on the underside of the arm cuff. A cable is attached from the compression spring in the wrist resistance mechanism to the wrist lever. As the wrist is extended, the cable compresses the spring thereby applying resistance to the wrist. The wrist lever is a strap across the back of the hand. The strap allows for a more even distribution of pressure across the hand during use.

The finger resistance is provided by a secondary, smaller linear extension spring. The finger resistance spring is connected from the wrist lever to the finger lever, providing resistance to the hand, independent from the wrist resistance. The extension spring attachment location on the wrist lever is variable to allow for adjustment of the resistance pre-load. The finger lever is coated with foam over areas of contact with the hand to maximize comfort during use.

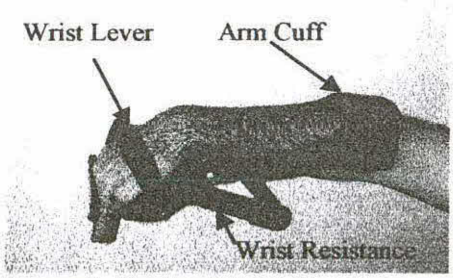

Figure 2. Hand and Wrist Flexed

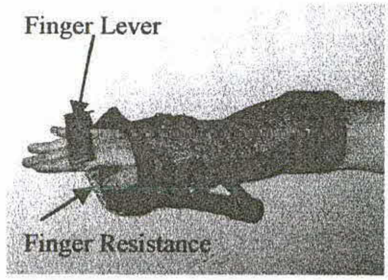

Figure 3. Hand and Wrist Extended

DISCUSSION

The functional prototype met the target design requirements. The arm cuff design is sturdy and the support points are well located. In addition, the arm cuff fits a wide range of forearm sizes. The finger lever is currently linked to the wrist lever only by the linear extension springs. The extension spring does not provide the structural integrity necessary to keep the finger lever from slipping off the fingers during use. Improvements will include developing a linkage to support the role of the spring. The ability to exercise the hand and wrist simultaneously results in a natural, effective and time efficient exercise experience.

Once the exerciser design is complete, potential users will evaluate it. Volunteers will be asked to use the exerciser for a period of one to two weeks. During the evaluation period, subjects will be asked to track their experiences with the device. Of particular interest are device comfort, ease of use, ease and appropriateness of resistance adjustment, aesthetics, and overall desire to use the device. Feedback from the user survey and supporting design information will be documented for future design iterations.

ACKNOWLEDGEMENTS

We would like to thank Peter Axelson, Mark Richter and the staff of Beneficial Designs Inc., as well as Tim Hight and Jeanne Linsdell for their support of this project.

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THE PRESSURE IS OFF! INTERFACE PRESSURE MAPPING IN THE HOME

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ABSTRACT

Interface pressure mapping (IPM) is now a portable system that can be used in the home by community therapists. This portable laptop system has been found to be effective in a variety of situations: (1) to compare the effectiveness of products such as wheelchair cushions; (2) to confirm pressure relief techniques such as push ups; (3) to provide compensatory visual feedback to clients who lack sensation; (4) to pressure map a client's atypical support surfaces such as car seat; (5) to monitor interface pressure after flap surgery; and (6) to confirm the proper inflation of a wheelchair cushion. The response by clients has been overwhelmingly positive when they were surveyed using the *Psychological Impact of Assistive Devices (PIADS)*.

BACKGROUND

Interface pressure mapping (IPM) has been used in seating clinics for a number of years. Recently, the technology has been used by manufactures to compare support surfaces such as mattresses (3). With the advent of rehabilitation services moving to community settings, how can technology such as IPM move with the clients? This paper describes the use of a portable IPM with individuals who lack full sensation in their buttocks and legs. **Visual** depiction of pressure distributions provides these individuals with an alternate feedback system. The clients sit or lie on their typical seating surfaces and view the IPM in real time. A colour printout is given to them to refer to at a later date and to educate their caregivers, physician and medical personnel.

STATEMENT OF THE PROBLEM

How do clients respond to the use of a real time portable interface pressure mapping device and procedure (i.e. what is the degree of customer satisfaction)? Does pressure mapping in their homes affect their choice of seating/lying surfaces? What assessment situations was the IPM used? Who was it being used with?

METHOD

The *Xsensor*™ interface pressure map system was used. The laptop computer was a Toshiba 220 CDS Pentium with 16 MB of RAM, Windows 95. The package also had a Hewlett-Packard DeskJet 340 portable colour inkjet printer. The laptop and printer were stored in a padded leather case. Two 24" x 24" *Xsensor*™ pads were used and stored in a large artist's portfolio. The pads were calibrated every 6 months. A strip thermometer was glued to the Xsensor™ interface box to monitor ambient temperature. Temperature was known to affect the results. The interface box was stored in a Pelican™ case.

A pressure mapping **protocol** was written and followed during each mapping session. Clinically relevant protocols for pressure mapping are critical for assisting with reliable interpretation of the data (1). A *Xsensor™ Pressure Mapping Data Collection Form* was completed for all clients. It collected demographic and medical background data for each client. In addition, the form collected information on the specific assessment situations that the IPM was being used for each client. The *Psychological Impact of Assistive Devices (PIADS)* was used to ascertain the clients' response to the interface pressure mapping procedure (2). This is a self-report measure that can be used to assess the impact of devices and procedures because it assesses perceived personal competence, adaptability and self-esteem. All clients were administered the *PIADS* by the home therapist.

RESULTS

The majority of the clients were spinal cord injured, male and lacked sensation on their buttocks and lower limbs. The results indicated that the IPM was used in a variety of community situations that included:

- The IPM was used to compare pressure distributions between various wheelchair cushions and support surfaces.
- The IPM was used to compare pressure distributions between various novel seating surfaces with and without cushions (e.g. saddle, all terrain vehicle, ski sled, car seats, bath seats).
- The IPM was used to assess the effectiveness of power tilt vs. recline to relieve pressure as well as the effectiveness of a client's own pressure relieving techniques (e.g. push ups).
- The IPM was used to monitor the interface pressures after flap surgery for pressure ulcer.
- The IPM was used as a **compensatory tool** (i.e. visual depiction of pressure) with clients who lack the somatosensory ability to feel pressure. This is done on discharge from hospital.

The clients surveyed with the *PIADS* indicated a high level of self-esteem and adaptability. Most clients requested changes in their seating or support surfaces. See **Figure 1** for an example of one client's decision based upon the IPM procedure. The majority of clients indicated that their decision making was influenced by the IPM data. Details of the client satisfaction survey will be provided.

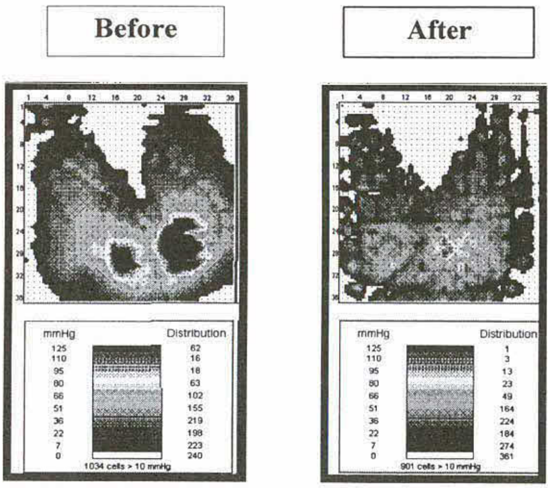

Figure 1. Mr. E.'s is a C_5 quadraplegic with a Stage IV ulcer under the right ischial tuberosity. His choice of cushions ***before*** the interface pressure mapping procedure is shown on the left. His present choice of cushions *after* the procedure is shown on the right. He rated the ***visual*** depiction of his pressure as increasing his self-confidence, competency and the ability to take advantage of opportunities.

DISCUSSION

The portable *Xsensor*™ interface pressure mapping system has been an effective tool used for a variety of purposes in the community as rated by clients. This procedure is particularly useful as rated by those clients who lack normal sensation due to a spinal cord injury. This IPM procedure has provided clients with the objective information to make informed decisions regarding their support surfaces. This IPM procedure is client-centered which has been supported by administration and many professional groups (e.g. Canadian Association of Occupational Therapists). Moreover, it supports the need for evidence based practice (4).
Reduction in the incidence of pressure ulcers is also a goal of this program. Although the initial expenditure is very high for an interface pressure-mapping device, it is hoped to decrease the incidence of pressure ulcers by reducing pressures effectively.

Interface pressure mapping is not without its drawbacks. It demands a lot of therapist time to complete the protocol. The average time is 2.5 hours. The complete system is still bulky and heavy to carry. The cables need to be longer in order to provide flexibility in a home for a variety of locations. The interface box should be battery operated to enable the system to be truly "portable". Lastly, most of the clients tested were privately funded by WCB. Therefore, changing their support surfaces was expedited quickly by using the IPM. All clients were given the funding to support their decision. This funding source may have influenced the results of the *PIADS* since there was no perceived barrier to making the change. Timely funding was seen as a very important issue.

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RESNA Student Scientific Paper Competition

Student Scientific Paper Competition
Sponsored by Whitaker Foundation

On the following pages, you will find the five award-winning papers for the sixth annual RESNA Student Scientific Paper Competition. The student awardee listed as the first author on each of the papers. These awards are supported through the generosity of the Whitaker Foundation. The purpose of the Student Scientific Paper Competition and awards is to encourage and promote student participation in high-quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the RESNA annual conference. This competition is based on scientific merit of the reported research and is structured to be distinct from, and complimentary to, the student design competition.

The winning papers are presented in a special session during the RESNA 2000 Conference. This session provides a unique forum which, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. Members of the Student Scientific Paper Competition Committee scored each paper after careful review based on the following criteria:

- General quality of the writing and presentation.
- Clear statement of hypothesis or research issues to be addressed.
- Choice and description of appropriate methodology
- Presentation of the results.
- Discussion of the results and their significance.

I would like to sincerely thank the review committee for this year's competition: Glen Ashlock, Geoffrey Fernie, Donn Hilker, Jane Huggins, Heidi Koester, Gerard Lacey, Tariq Rahman, Steven Reed, Cameron Riviere, Larry Schneider, and Jon Schuch. They faced very difficult decisions in choosing the five winners as most of the papers were deemed meritorious.

On behalf of RESNA, I wish to thank the Whitaker Foundation for its support , the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their research for submission to the 2001 RESNA Student Scientific Paper Competition.

Richard Simpson, PhD ATP
Chair, RESNA Student Scientific Paper Competition

PERFORMANCE EVALUATION OF COMMAND CONTROL ALGORITHMS FOR UPPER-EXTREMITY NEUROPROSTHESES

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ABSTRACT

The goal of this study was to evaluate the performance of command control algorithms for upper-extremity neuroprostheses. Subjects completed an acquire-hold-modify task using a computer-based video simulator of neuroprosthetic hand grasp. The subjects controlled a video-simulation of a hand using seven different command control algorithms. Success rate on the task was used as a measure of performance, and a generalized estimating equations-based model was used to analyze the data. Algorithms that used rectification of the command signal or variable gain were superior to the present algorithm, while those that used time-based control were inferior. The rectification and variable-gain algorithms should be evaluated further in a clinical setting.

BACKGROUND

Functional electrical stimulation (FES) is used to restore hand grasp to individuals with tetraplegia [2]. Upper-extremity neuroprostheses using FES restore three actions of the hand: hand opening, or decreasing force, hand closing, or increasing force, and steady position or force (lock). Contralateral shoulder position is often used as a control source, providing both graded control and logical signals [3]. A map must be created between the shoulder position and the muscle stimulation to achieve control of hand opening, closing, and lock. This map is referred to as a command control algorithm.

The command control algorithm currently in use in the upper-extremity neuroprostheses (lock-only algorithm) provides proportional control, where hand opening/closing is proportional to shoulder elevation, and the ability to lock via a rapid shoulder elevation [3]. To adjust the hand after locking, the user must unlock the hand via another rapid shoulder elevation and realign the shoulder position to where the lock was entered before regaining proportional control. This is a slow and difficult process. Therefore, new command control algorithms were developed which allow adjustment of the force value after the hand is locked.

RESEARCH QUESTION

The objective of this study was to identify possible replacements for the lock-only algorithm by evaluating different command control algorithms on a consistent task. We hypothesized that using new control algorithms would improve the success rate for completing an acquire-hold-modify task relative to the lock-only algorithm. The five algorithms tested against the proportional control and lock-only algorithms used various combinations of three features: rectification (allowed changing command value after lock), gated-ramp (time-based control), and variable-gain control (provided lower controller gain during manipulation).

METHODS

Simulator: Approval for human testing in this study was granted by the MetroHealth IRB and informed consent was given by each subject. All testing of the command control algorithms was done with a computer-based video simulator of neuroprosthetic hand grasp [4]. The simulator provided an able-bodied subject with a video display of a neuroprosthesis user's hand. The subject wore a shoulder position sensor and used shoulder elevation and depression to control the command input to the video-based hand grasp.

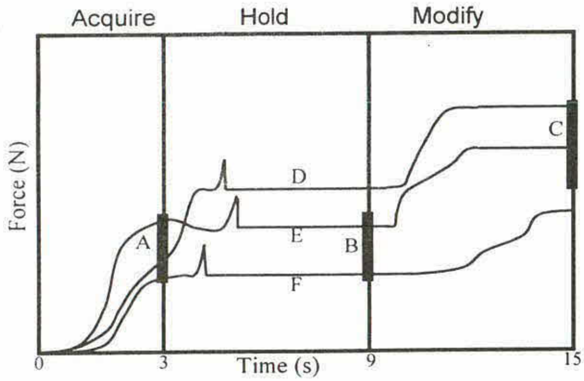

Figure 1. *Sample evaluation task. A-C are force windows for each phase. D-F are sample trails. E is successful, while D and F are failures.*

Evaluation Task: The subject used shoulder position to vary the force as a function of time to complete an acquire-hold-modify task using visual feedback from the video image without direct knowledge of grasp force. The task (Figure 1) required the subject to attain a grasp force within a specified force window (Figure 1 A-C) during each phase of the task. Finishing all three phases within the required window constituted a successful trial. The subject was verbally informed of the outcome of each phase immediately following each trial.

Testing of Control Algorithms: The seven control algorithms were tested on five able-bodied subjects. Each subject tested each algorithm twice across 6 sessions. The order of presentation of algorithms was counterbalanced to minimize biasing.

After five practice trials, the subject completed 15 recorded trials (one block of trials). The subject was allowed to view the force display during the practice trials, but not during the recorded trials. The percentage of successful trials in each block was recorded for three force target window sizes (large, medium, and small) for the proportional control algorithm and two other control algorithms during each session.

Data Analysis: A linear model in the following form was used to analyze the data: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots$, where Y was the log-odds ratio of the predicted success rate, X_n was a factor term, and β_n was a coefficient of the model determined through generalized estimating equations. The β_n determined how much each factor affected the output of the model. The coefficients for each control algorithm except the proportional control were compared to the coefficient of the lock-only algorithm using contrast analyses.

RESULTS

Figure 2 shows the success rates for each algorithm, pooled across subjects and data sets, as a function of the force target window size. These data show that the performance of the variable-gain

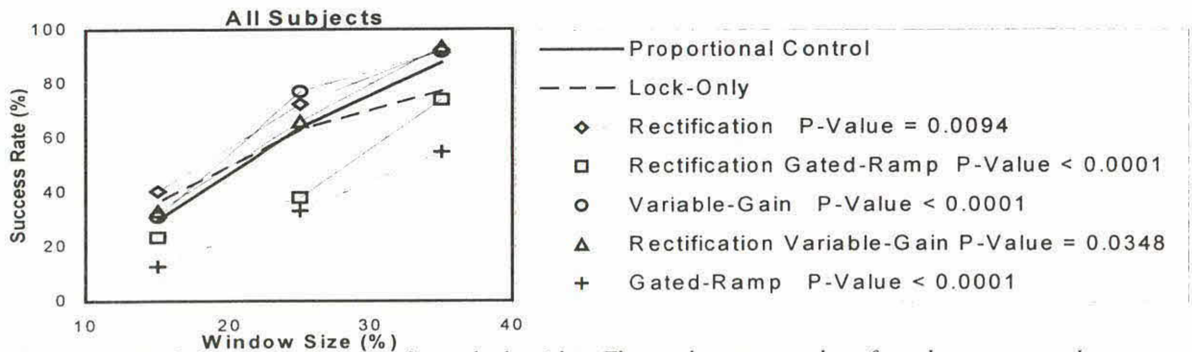

Figure 2. *Pooled success rate curves for each algorithm. The p-values presented are from the contrast analyses between the model coefficients of each algorithm and the coefficient for the lock-only algorithm.*

and rectification algorithms were better than the performance of the lock-only algorithm, while the performances of the gated-ramp and rectification gated-ramp algorithms were worse. The p-values from the contrast analyses showed that these relationships were statistically significant.

DISCUSSION

A computer-based video simulator was used in this study to collect large amounts of information by allowing a large range of subjects (including able-bodied) to test command control algorithms on a consistent task. The use of such a simulator for evaluating control methods was shown to be reliable by Durfee [1], but drawbacks to using the simulator with able-bodied subjects should be taken into consideration. The simulator does not account for fatigue, hysteresis, shoulder motion extraneous to prosthesis command control, and other factors that may affect performance. Further, able-bodied subjects have more control over shoulder movements than individuals with tetraplegia, which may decrease the applicability of these results [3]. Still, the simulator serves to identify promising command control algorithms that can be evaluated further in a clinical setting.

Although created specifically to test the algorithms in this study, the evaluation task has relevance to daily activities of neuroprosthesis users. The task always required the subject to increase the force during the modify phase. By forcing the subject to decrease the force, it is likely that most of the algorithms would yield similar performances. The level of difficulty in the modify phase was high because a region of high slope existed in the non-linear force recruitment curve (force output vs. command value) [2]. This high slope region may have biased the results toward the variable-gain algorithms. However, since this curve was based on empirical data, it increased the realism of the simulation.

CONCLUSIONS

Time-based control should not be chosen as a replacement for the lock-only algorithm. The rectification and variable gain algorithms did improve performance significantly, and should be tested clinically. The functional outcome of this increase in performance is that using either of these algorithms is similar to operating the lock-only algorithm at a larger target force window size.

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FEASIBILITY OF RESTORING SHOULDER FUNCTION IN HIGH LEVEL TETRAPLEGIA

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ABSTRACT

Individuals with high level spinal cord injury (SCI) retain little or no voluntary control over their arm musculature, limiting their ability to perform activities of daily living. Three subjects with C3 and C4 tetraplegia were implanted with percutaneous electrodes in a set of shoulder and elbow muscles. Muscle strength was characterized through measurements of the shoulder and elbow moments elicited by maximal stimulation of the implanted muscles. A musculoskeletal model of the shoulder and elbow was modified to reflect stimulated muscle strength, and simulations were performed to evaluate the feasibility of restoring shoulder function in these individuals using functional neuromuscular stimulation (FNS).

BACKGROUND

Individuals with high level SCI retain little voluntary control over arm function, limited to shoulder shrugging and retraction-protraction through the use of the levator scapulae and upper trapezius muscles. These individuals depend on attendant care for all activities of daily living. Most rehabilitation interventions designed for this population use assistive technology that allow some interaction with the environment. However, it would be desirable to provide these persons with arm movements that allow them to independently perform daily activities such as feeding or grooming.

The use of FNS combined with orthoses for restoring elbow and hand function has been investigated by several research groups (1-3). They all reported limitations in the performance of their systems mainly due to lack of shoulder control. Shoulder muscles receiving innervation from the C5 level may be denervated in persons with high level SCI, especially those with C4 tetraplegia. However, the extent of denervation will depend on the level and type of injury, and is likely to vary across individuals.

The shoulder system is mechanically complex, consisting of several articulations that provide the arm with the greatest range of motion of any other limb in the human body. The coordinated action of several muscles is required to provide arm movement and shoulder stability. Due to this complexity, restoring shoulder function in individuals with high level SCI becomes a challenging task. Further understanding of shoulder biomechanics is needed in order to design reliable systems that restore shoulder movement and stability. Musculoskeletal models (5) may be a useful tool to gain more insight into shoulder biomechanics and to aid in the design of rehabilitation interventions such as FNS.

RESEARCH QUESTION

The goal of this study was to evaluate the feasibility of restoring particular arm postures in three individuals with C3 and C4 tetraplegia. More specifically, the objectives were to determine the shoulder and elbow muscle strength resulting from FNS and to perform model simulations to determine the feasibility of restoring these functions with the stimulated muscle strengths.

METHODS

Three subjects participated in the study. One subject with C3 tetraplegia (Subject 1) and two with C4 tetraplegia (Subjects 2 and 3). Percutaneous stimulating electrodes (4) were implanted into the

Anterior Deltoid (AD), Posterior Deltoid (PD), Infraspinatus (I), Pectoralis Major (PM) - clavicular (PMC) and thoracic (PMT) heads, Latissimus Dorsi (LD), Biceps (BIC) and Triceps (TRI) muscles bilaterally in two of the subjects and in the right arm of Subject 1. After a period of two weeks to allow stabilization of the electrodes, a stimulation exercise paradigm was initiated to restore muscle strength and increase the muscle resistance to fatigue. Measurements of stimulated shoulder strength were obtained at least 9 weeks after implant.

Maximum contractions of the implanted muscles were elicited by applying a biphasic, charge balanced stimulus to each electrode. The current pulses were set to 20 mA, 12 Hz, with a maximum pulse width of 200 μsec. The subject's arm was attached to a 6-axis force transducer mounted on a frame that allows free positioning of the limb. The forces and moments elicited by stimulation of the individual shoulder muscles and combinations of muscles were recorded and transformed off-line to reflect the moments produced at the shoulder joint (Figure 1). The elicited elbow moments were recorded using a device instrumented with strain gauges to measure the torque produced in flexion or extension.

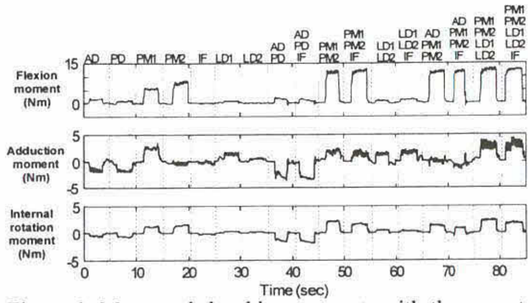

Figure 1. Measured shoulder moments with the arm at 90° elevation in the coronal plane.

Maximum muscle forces (muscle strength) were calculated for Subject 1 based on the measured shoulder and elbow moments and the muscle moment arms from the musculoskeletal model. These maximum muscle forces were used to modify the musculoskeletal model. Inverse simulations were performed with the modified model to assess the shoulder capabilities with the implanted set of muscles, as well as with augmented sets of muscles and "stronger" muscles.

RESULTS

Stimulation of all the implanted muscles in all three subjects (5 arms) elicited contractions of varying magnitude (Table 1). The elicited shoulder moments in Subject 1 (C3 level SCI) were greater than in the other two subjects (C4 level SCI) as expected from the level of injury and the accompanying extent of denervation occurring at the C5 level. Subjects 2 and 3 had weak Deltoid muscles, which could not be stimulated to produce abduction moments sufficient to hold the arm against gravity. The strongest muscles for all subjects and all arms were the Pectoralis Major, Latissimus Dorsi and Triceps muscles which receive innervation from C6 and lower levels of the spinal cord. The weakest muscles were the Deltoids and Biceps which receive C5 and C6 level innervation.

Moment (N·m)		Subject 1	Subject 2		Subject 3	
		Right Arm	Left Arm	Right Arm	Left Arm	Right Arm
SHOULDER	Flexion	12.91	0.65	3.24	10.73	4.58
	Extension	3.73	0.42	2.38	5.59	3.81
	Abduction	7.54	0.40	1.04	1.85	3.81
	Adduction	5.94	1.56	5.02	9.19	7.50
	Int. Rotation	2.70	0.67	2.25	2.91	3.32
	Ext. Rotation	3.59	0.26	1.20	0.90	0.91
ELBOW	Flexion	0.89	0.60	2.70	0.54	1.06
	Extension	4.38	10.35	1.78	2.83	2.92

Table 1. Maximum shoulder and elbow moments resulting from electrical stimulation.

As shown in Table 2, the estimated muscle forces in Subject 1 were between ~7% (PD) and >100% (PM) of able-bodied maximum muscle strength (as obtained from the model). Table 3 summarizes the results from the inverse static simulations performed with the modified model. The model predicted the inability of the subject to hold the arm against gravity in the coronal plane. "Adding" the other rotator cuff muscles (Supraspinatus, Subscapularis and Teres Minor), the Serratus Anterior muscle, and increasing the strength of the Deltoids by 20% and of Biceps by 40%, resulted in the ability to hold the arm against gravity through its range of motion in the coronal plane.

Muscle	Maximum Force (N)	% of able-bodied
Anterior Deltoid	132.98	16.47
Posterior Deltoid	113.50	6.85
Pectoralis Major	1985.60	>100
Latissimus Dorsi	318.74	39.01
Infraspinatus	71.86	8.43
Biceps	39.93	11.41
Triceps	147.54	9.57

Table 2. Estimated maximum muscle forces for Subject 1.

Muscle sets and muscle strength	Elevation Angle						
	10°	30°	60°	90°	115°	140°	160°
Voluntary + Implanted Set	X	X	X	X	X	X	X
+ Rot.Cuff (50%) + S.A.(50%)	X	X	X	X	X	X	✓
+ ↑ AD, PD and BIC by 10%	✓	X	X	X	X	X	✓
+ ↑ AD, PD and BIC by 20%	✓	✓	X	X	X	✓	✓
+ ↑ AD, PD by 20%, BIC by 40%	✓	✓	✓	✓	✓	✓	✓

Table 3. Model simulation results: required muscle set and muscle strength to maintain the arm (✓) at particular elevation angles in the coronal plane.

DISCUSSION

The simulation results indicate that restoring shoulder function in individuals with high level tetraplegia requires a minimum set of muscles that must be included in a FNS system. Such muscles not only act to provide movement (e.g. Deltoids) but also stability (e.g. rotator cuff) to the shoulder. Based on comparison with contractions resulting from stimulation with surface electrodes, we believe that some of the muscles (e.g. Biceps) were not being recruited completely by the stimulus delivered to the percutaneous electrodes. Improved stimulation methods that provide more complete muscle recruitment, such as nerve cuff electrodes, should be examined. Denervation is the main obstacle when implementing FNS systems to restore shoulder function in subjects with high level SCI. Alternative procedures that restore or replace the denervated muscles key in restoring function must also be examined. Such procedures include external mechanical devices and surgical procedures such as muscle tendon transfers. Future work will assess the effectiveness of these procedures through biomechanical simulations.

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PROACTIVE BALANCE WHILE MAINTAINING A STATIONARY WHEELIE

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ABSTRACT
We tested the hypothesis that maintaining wheelies requires a reactive balance strategy to maintain dynamic stability (pitch followed by rear wheel displacement in the same direction). After training and videotaping ten able-bodied subjects to perform wheelies, our subjects spontaneously adopted what we believe to be a proactive balance strategy (pitch simultaneous with displacement in the opposite direction). Subjects appeared to use a functional base of support that was larger than the geometric one. These findings have particular significance for those who are learning and teaching wheelies and provide insight into the nature of dynamic balance.

INTRODUCTION
Although much research has been conducted regarding wheelchair propulsion, there is little in the literature about the wheelchair wheelie (1-5). A wheelie is executed when the user pops the front casters off the ground and balances on the rear wheels. A wheelie is useful in a variety of situations, for instance when an individual must climb a curb, turn in confined spaces or negotiate uneven terrain (1,2).

To understand wheelie balance, it may be helpful to consider the analogy of standing balance. Postural stability, during quiet standing, is the ability to control the position of the center of mass (COM) with respect to the base of support (BOS). In the case of the stationary wheelie, static balance is almost impossible due to the small BOS. Perturbations would appear to require the wheelchair user to react by exerting forces on the handrims to rotate the rear wheels, thus translating the BOS under the COM, most analogous to the step strategy of standing balance. This theory of a reactive balance strategy to maintain wheelies, although it makes teleological sense and is assumed to be the case by a number of authors (1-5), has not been quantified or validated.

PURPOSE
The primary purpose of this study was evaluate whether the reactive strategy is indeed used to maintain a stationary wheelchair wheelie. Specifically, we hypothesized that a forward pitch from the wheelie equilibrium position would be associated with a forward displacement of the wheelchair and a rear pitch would be associated with a rear displacement of the wheelchair, with the displacement slightly following the change in pitch. A secondary purpose was to quantitate the pitch changes and linear displacements of the wheelchair during these activities.

METHODS
We studied 10 able-bodied subjects with their informed consent. To control for variability among wheelchairs, we used a single lightweight, rear-wheel-drive manual wheelchair for all training and testing. The subjects' mean (standard deviation [SD]) age, height and weight were 20.9 (1) years, 1.70 (0.06) m and 66.2 (8.6) kg respectively.

Subjects attended three 30-minute training sessions to learn to perform three wheelie skills: 1) popping and maintaining a stationary wheelie for 15 s while remaining in a 0.75 by 0.75 m square, 2) rolling forward 1.0m while in a wheelie position, and 3) rolling backwards 1.0m while in a wheelie position. Although we only studied the first of these skills (maintaining a wheelie), we taught the other two because we wanted subjects to have more than a minimal skill level.

Once the subjects could perform the three skills, we videotaped them performing 3 stationary wheelies. We placed digitizing targets on the center of the rear axle and on the anterior chair frame above the footrests. We instructed subjects to perform a stationary wheelie for 15 s, while remaining in a 0.75 by 0.75m square. Each subject performed 3 15-s trials, of which the middle 5 s of the final 2 trials were digitized.

We calculated descriptive statistics and plotted the pitch angle and linear displacement of the wheelchair against time. We used time-series analysis and cross-correlation with each digitized trial (n=20) to determine if phase-lags were present between the pitch and displacement of the wheelchair. Correlations were calculated from k=-20 to k=20, with each change in k corresponding to a shift of 1/60s of the pitch data relative to the displacement data. The k-value resulting in the maximum correlation indicated the extent of any time-lag between the two data sets.

RESULTS

Most subjects learned to perform the three wheelie skills within one or two training sessions, but one subject required three sessions. Subjects indicated that rolling backwards while in a wheelie was the most difficult, whereas the stationary wheelie was the least difficult.

A representative plot of wheelchair pitch angle and linear displacement is shown in Figure 1. Qualitatively, there was an inverse relationship between the direction of pitch and the direction of linear displacement of the wheelchair in all 20 trials. The mean (SD) pitch angle was 13.6 (2.3)° with a mean range of 5.4 (4.4)° (median=4.1°). The mean range of rear-wheel linear displacement was 11.0 (8.1) cm (median=7.3 cm).

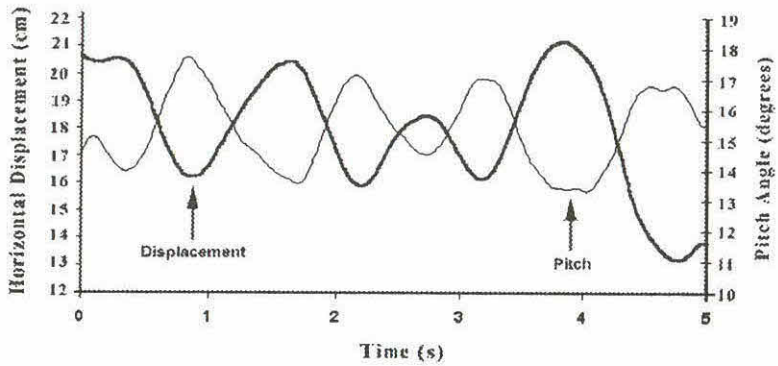

Figure 1. Representative plot of wheelchair pitch angle and rear-wheel horizontal displacement during a 5-second stationary wheelie. Pitch angle is measured relative to the horizontal where an increase in pitch indicates a pitch in the rear direction. Horizontal displacement is measured relative to the fixed origin on the video data where an increase represents a displacement in the rearward direction.

In 15 of the 20 trials we found a maximum correlation between pitch angle and linear position of the wheelchair at k=0 on the time-series analysis. In five trials, the maximum correlation occurred after a time shift in the data, with the changes in linear position from 1/60 to 5/60 seconds after the changes in pitch.

DISCUSSION

In the setting that we studied, a group of moderately skilled subjects quietly maintaining a stationary wheelie, the reactive strategy hypothesis was refuted. Indeed, we found strong evidence of the converse -- as the wheelchair pitched in one direction, the chair rolled in the opposite direction. In the majority of trials, there was little or no phase lag between these events.

Maintaining balance during a stationary wheelie in the way that we have documented appears to be a proactive strategy. The COM and the BOS oscillate about the equilibrium point of the system while in a state of dynamic equilibrium. Wheelie equilibrium is an example of metastability where any small deviation away from the equilibrium point will cause the wheelchair to fall (3,4). But, if the perturbations are known (forward and backward pitch), the person may be able to prevent the perturbation by using the rhythmic pattern we have described. The wheelie performer may be "staking out" a functional (or "virtual") BOS that is larger than the geometric one. This functional BOS would provide the wheelie user with a larger area in which to maintain balance.

In conclusion, subjects maintaining a quiet stationary wheelie use a type of balance strategy that has not been previously described. The characteristic of this strategy is the simultaneous change in wheelchair pitch angle and rear-wheel position such that forward pitch is accompanied by rearward wheel movement and rearward pitch by forward wheel movement. This finding has significance for people learning to perform wheelies and also sheds new light on the nature of dynamic balance in metastable conditions.

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EXCURSION AND STROKE FREQUENCY DIFFERENCES BETWEEN MANUAL WHEELCHAIR PROPULSION AND PUSHRIM ACTIVATED POWER ASSISTED WHEELCHAIR PROPULSION

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ABSTRACT

Upper extremity injury in the manual wheelchair user (MWU) is thought to be caused by excessive excursion and stroke frequency. The purpose of this study was to examine the efficacy of a pushrim activated power assist (PAPA) wheel in the reduction of joint excursion and stroke frequency. Ten MWU's were examined for joint excursion and stroke frequency while using their own wheelchair and a wheelchair equipped with PAPA wheels. The use of PAPA wheels significantly ($p<0.05$) decreased upper extremity excursion. Stroke frequency was altered little. These findings suggest that the use of PAPA wheels may decrease the risk of upper extremity injury in the MWU population.

INTRODUCTION

Upper extremity pain and injury is prevalent among manual wheelchair users (MWUs). Incidence of shoulder pain has been reported to be as high as 51% in this population (1). Furthermore, the prevalence of pain in the elbow, wrist, and hand has been reported to be 16%, 13%, and 11%, respectively, among MWUs (2). The upper extremity pain and injury associated with manual wheelchair use is often attributed to overuse and excessive range of motion of the involved joints (1,2,3).

The repetition of motion involved with manual wheelchair use is thought to lead to repetitive strain injuries (RSI) of the upper extremities. These RSI's involve damage to the soft tissue of the involved joints. In addition, extreme ranges of motion (ROM) or excursion of a body part is believed to increase the incidence of upper extremity neuropathies (4). For MWUs, the pain and injury caused by repetitive motion and excessive excursion may lead to loss of independence, decreased activity, and additional secondary injuries.

The purpose of this investigation was to examine the use and efficacy of a pushrim activated wheel (Yamaha JWII, Yamaha Motor Corporation, Japan) as a method for decreasing excursion and propulsion frequency in MWUs. The Yamaha JWII pushrim activated wheel provides proportional torque based on the users input torque to the pushrims. In other words, the greater the torque supplied to the pushrim by the user, the greater the torque generated by the JWII wheel, in effect making propulsion easier.

METHODS

Subjects. A random sample of ten MWUs gave informed consent to participate in this study. The subject sample consisted of six males and four females aged 22 to 50 (mean 34.5, SD10.6). All subjects reported to be free of pain and pressure sores at the time of this study.

Kinematic Measurement System. Kinematic data were collected during the final 30 seconds of a three-minute trial using a 60 Hz, three-dimensional camera system (OPTOTRAK, Northern Digital Inc.). LED markers, used for kinematic analysis purposes, were placed on the subject's acromion process, lateral epicondyle, ulnar styloid, third metacarpophalangeal (MP) joint, and the wheelchair hub.

Experimental Protocol. Testing was performed in a random order repeated measures design. Each subject was examined for joint excursion and propulsion frequency while propelling their own wheelchair or a Quickie 2 manual wheelchair equipped with Yamaha JWII pushrim activated wheels. Seat dimensions were kept consistent between wheelchairs.

Subjects were fitted with the LED markers and checked for impediment of upper extremity ROM. The subjects propelled on a wheelchair dynamometer at the selected resistance (9, 12, 13, 21, or 27 Watts) and speed (0.9 m/s or 1.8 m/s) for three-minutes and then rested for approximately three minutes. This process continued for all five trials involving the selected wheelchair. The second wheelchair was then tested in the same fashion. The LED markers were undisturbed during the wheelchair change over.

Data Analysis. The data was analyzed for excursion of the right acromion process, lateral epicondyle, and third MP joint in the sagittal (x,y) plane during the first five propulsion strokes recorded. The data was also analyzed for stroke frequency. The relation of the acromion process to the wheelchair hub was analyzed to discern differences between the subject's position in their own wheelchair and the Quickie 2 pushrim activated wheelchair.

Statistical Analysis. A paired sample t-test was used to compare mean excursion and stroke frequency. When data was found to be unevenly distributed, a Wilcoxon signed ranks test was performed. Significance was set at the $p=0.05$ level.

RESULTS

Data analysis revealed significant decreases in excursion of the right, third MP joint, lateral epicondyle, and acromion process in both the x- and y-direction for several resistances and speeds while propelling the pushrim activated wheelchair ($p<0.05$) (Table 1). Stroke frequency was found to be significantly increased for the high resistance, low speed trial when using the pushrim activated wheelchair ($p<0.05$).

DISCUSSION

MWUs are at risk for developing upper extremity injury and neuropathies due, in part, to repetitive motion and excessive excursion of the involved joints. For this reason, the efficacy of a PAPA wheel was examined for its ability to decrease joint excursion and stroke frequency.

The results of this study reveal that use of the Yamaha JWII pushrim activated wheel significantly decreases the excursion of the upper extremity joints needed for wheelchair propulsion at common resistances and speeds. However, stroke frequency was altered little by the use of the JWII. Stroke frequency is believed to remain nearly constant during manual wheelchair propulsion at different speeds and resistances. This is due to alterations in the individuals time on the pushrim and force imparted to the pushrim rather than more or fewer propulsion cycles. The fact that stroke frequency increased when using the pushrim activated wheels at a moderate resistance may be explained by the force needed to propel at this resistance. The force imparted to the pushrim activated wheels is believed to be less than the subject's own wheelchair pushrim but the frequency of that force must be higher in order to maintain the 0.9 m/s speed.

Two different wheelchairs were used for comparison in this study. This was due to the unique needs of the wheelchair accommodating the JWII wheels, however, the propulsion biomechanics used from chair to chair may differ. To discern any differences in propulsion biomechanics an examination of the relation of the acromion process to the wheelchair hub of both wheelchairs was made. This examination revealed the positioning of the users in each chair to be comparable and, therefore, the propulsion biomechanics between wheelchairs was deemed comparable (5).

Table 1 Mean Excursion Values (mm)

	Third MP				Lateral Epicondyle				Acromion Process			
Trial	JWII		No JWII		JWII		No JWII		JWII		No JWII	
	x	y	x	y	x	y	x	y	x	y	x	y
9 Watts 0.9m/s	**354**	**147**	426	183	**216**	126	257	153	27	16	39	19
21 Watts 1.8m/s	506	152	482	157	269	154	292	157	35	19	38	23
12 Watts 0.9m/s	344	124	434	162	**215**	140	248	146	25	17	37	17
27 Watts 1.8m/s	395	**130**	433	156	**253**	**135**	290	162	32	**18**	43	23
13 Watts 0.9m/s	**440**	**141**	453	171	**201**	**124**	255	150	**22**	13	30	13

* Bold denotes significant difference between JWII and No JWII

CONCLUSION

The findings of the present study demonstrate the Yamaha JWII's ability to significantly reduce the excursion of upper extremity joints during wheelchair propulsion. The use of these pushrim activated wheels may reduce the incidence of upper extremity injury and neuropathies in the MWU population. The JWII wheels will also give clinicians and MWUs greater choice when prescribing and choosing a wheelchair.

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WHEELCHAIR SEATING SYSTEM CRASHWORTHINESS: AN EVALUATION OF SEATING SURFACE ATTACHMENT HARDWARE

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ABSTRACT

Recognition of the importance of the vehicle seat in providing crash protection has increased in recent years. Automotive seats require extensive testing to assure compliance with government crashworthiness and occupant protection regulations. For wheelchair users that are not able to transfer to an automotive seat during transportation, the wheelchair itself must provide adequate protection to the occupant in the event of a crash. This study evaluated the crashworthiness of hardware that attaches seat and seat back surfaces to the wheelchair frame using a static load test procedure. Specifically, drop hook type hardware was assessed in this study. Eleven unique sets of hardware were tested. None of the hardware sets tested met the crashworthiness test criterion. All hardware failed at less than 50% of the load that may be experienced in a 20g frontal impact.

BACKGROUND

There has been an increase in recognition of the importance of vehicle seats in providing crash protection. Automotive seats must pass crashworthiness and occupant protection regulation as described by federal motor vehicle safety standards (FMVSS). Despite an effort by an ANSI/RESNA standard (WC-19) (1) to evaluate wheelchair crashworthiness, the addition of often used after-market or optional wheelchair seating systems will invalidate testing and many wheelchairs with add-on seating systems will not be sled tested to evaluate their ability to withstand crash level forces. The proposed test method seeks to evaluate seat attachment hardware's ability to withstand the static equivalent of forces it would experience in a 20g/30mph frontal impact. Drop hooks were selected for evaluation because of their prevalence in the wheelchair seating industry.

RESEARCH QUESTION

When used on a wheelchair serving as a motor vehicle seat, is commercially available wheelchair seating system attachment hardware capable of maintaining structural integrity during a 20g/30mph frontal impact?

METHODS

The hardware to be tested was attached to a surrogate seat surface. The wooden surrogate seat was reinforced with steel at the attachment points to minimize deformation of the seat during testing. The seat-hardware structure was then attached to a wheelchair test frame consisting of two 1-in. diameter parallel bars positioned 18 inches apart (see Figure 1). This test fixture is intended to replicate a wheelchair frame and eliminates any wheelchair frame deformation so as to focus on seating and attachment hardware performance alone.

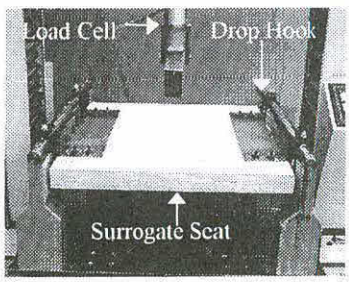

Figure 1: Test Setup

A load was then applied using an Instron Series 4200 test device, which is designed to test materials in either tension or compression. Loads were transmitted to the surrogate seat surface using the upper leg/buttock unit of the ISO 7176-07 test dummy, a reference loader gauge (RLG), which was "designed to simulate the dimensions and mass distribution of the human body"(2).

The magnitude of the test load was based upon a combination of computer crash simulations, limited sled testing, and FMVSS 207 test criterion. During a frontal impact the occupant imposes a downward load on the horizontal seat surface. The maximum seat force during a 30mph/20g frontal impact was found to be approximately 3750 lb.(3).

The hardware was deemed acceptable if it was able to support the applied test load for five seconds. Failure was defined as fracture or excessive deformation leading to an unstable surface condition.

The protocol for loading was:

- Apply load by moving the crosshead of the Instron at 20 in./min. (The actual rate of loading will depend on the stiffness of the hardware being tested.)
- Load to 3750 lb. and hold for five seconds. This is necessary to evaluate any stress relaxation in the test setup.
- Release the load at 20 in./min.

The load was measured using a load cell integrated into the Instron machine. The load and deflection were recorded with a sampling rate of 4 Hz for later analysis.

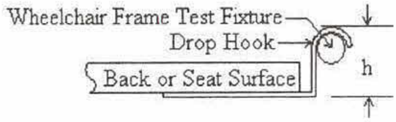

Figure 2: Drop Hook Attachment Hardware

The hardware tested was all of a drop hook design. Drop hooks were attached to a surrogate seat surface and wheelchair frame test fixture following the manufacturer instructions. In all cases four drop hooks were used to attach the surrogate seat surface to the test fixture. The design of the drop hook is shown in Figure 2. The height (shown as "h") of the drop hook is indicated when referring to the drop hook (i.e. 3" Stainless Steel). Eleven unique sets of hardware were tested following the described protocol.

RESULTS

Of the seating hardware tested, none were able to withstand the 3750 lb. simulated crash load without failure. Table 1 shows the failure load for each of the drop hooks tested. The maximum sustained load of any specimen was 1625 lb.; less than 50% of the target load.

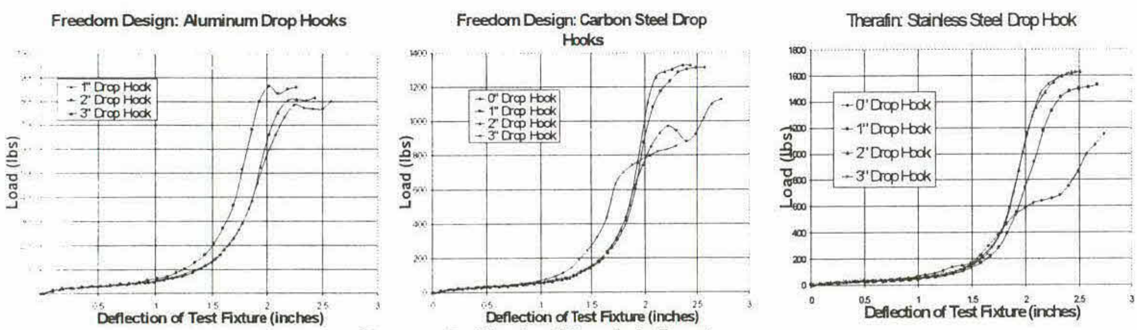

Figure 3. Typical load deflection curves

Table 1. Summary of Hardware Failure Loads

Drop Hook Size Tested "h"	Material	Failure Load (lbs)
Therafin 0"	Carbon steel	1129
Therafin 1"	Carbon steel	1313
Therafin 2"	Carbon steel	1328
Therafin 3"	Carbon steel	855
Freedom Design 0"	Stainless steel	1153
Freedom Design 1"	Stainless steel	1527
Freedom Design 2"	Stainless steel	1629
Freedom Design 3"	Stainless steel	1625
Freedom Design 1"	Aluminum	801
Freedom Design 2"	Aluminum	859
Freedom Design 3"	Aluminum	816

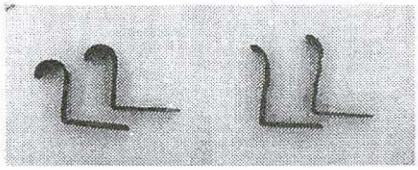

Figure 4: Drop Hook Failure Mode (left) Drop hook prior to testing and (right) drop hook after failure.

The factors that lead to the failure of the drop hook included material properties and hook geometry. The aluminum hooks failed at a lower load than the steel hooks due to their lower tensile strength. As the drop hook is loaded, the portion that wraps around the wheelchair test frame straightens. The failure occurred in stages as shown on the load/deformation curves (Figure 3). Note the plastic deformation that occurred indicated by the decrease in slope. It was at this point that the hooks were sliding past the wheelchair frame and the system was not able to hold any additional load (Figure 4).

CONCLUSIONS

The inability of a wheelchair seating system or seating component to maintain integrity during a motor vehicle crash can lead to increased risk of injury. Preliminary static testing, intended to replicate loading conditions experienced in a frontal crash, indicates that drop hook seating attachment hardware may not be capable of maintaining a stable seating surface necessary to support the occupant. All tested seating hardware failed through excessive deformation at loads that were less than 50% of expected maximum seat crash loads. Additional testing is planned to validate proposed test methods and to evaluate other types of seating hardware.

ACKNOWLEDGEMENTS

This effort was supported by PVA-SCRF, CDC-CIRCL, and the NIDRR-RERC on Wheeled Mobility. Opinions expressed are those of the authors and do not necessarily represent those of the funding agencies.

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RESNA Student Design Competition

RESNA Student Design Competition
Sponsored by Paralyzed Veterans of America (PVA)

The RESNA Student Design Competition recognizes the exemplary work of students in the many disciplines comprising the field of Assistive Technology. This year, a total of 28 entries were submitted, from student teams having the interdisciplinary profile of our field.

Designs were judged with respect to the following criteria:

- Appropriateness with respect to real user needs
- Input from intended users or manufacturers
- Innovation and creativity
- Manufacturability and market potential
- Cost to end-user
- Technical competence
- Documentation
- Working prototype or model

Award winners have made a special effort to bring their designs to the Conference. Please visit the Student Design Competition display, to make their efforts worthwhile.

Continued thanks are in order for the support provided by the Paralyzed Veterans of America (PVA). Through this support, PVA helps insure that individuals with disabilities will have access to the cutting-edge technology provided by skilled professionals. At PVA, Joan Napier is not only an advocate for the Student Design Competition, but an active part of the review and award process. Her work in this area was of great assistance.

As with many other RESNA activities, Susan Leone provided much help, guiding the process along, keeping things on schedule, and providing advice when questions came up. Her efforts were indispensable, as usual.

The difficult process of analyzing the designs was carried out with skill by an interdisciplinary panel, who generously devoted the time essential for a thorough and fair review. PVA and RESNA are indebted to them.

Finally, thanks must go out to all students who submitted entries. Choosing five designs for the award was as tough as ever.

Glenn Hedman, MEng ATP
Chair, Student Design Competition

BOCCIA RAMP USED BY THOSE WITH SEVERE MOTOR IMPAIRMENTS

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ABSTRACT

In order to compete in the popular wheelchair sport, boccia, an assistive device is necessary for those who are physically disabled from throwing the ball themselves. A ramp which is easily adjusted to control ball velocity is very important for competition. The device described in this paper is an attempt to solve this problem.

BACKGROUND

Italian in origin, boccia is one of the fastest growing sports, popular for handicapped/wheelchair athletes. It is a sport requiring great concentration and focus. Boccia provides athletic therapy through coordination movements, and mental thought. Competition takes place on the regional, national, and international levels. Its popularity has increased so much in recent years that it became a Paralympic sport for the 1992 Barcelona games. The basic idea of the game is for the athlete to throw, kick, or use an assistive device to propel a ball down a court in an attempt to get as close as possible to a target ball called the 'jack'. Each player gets to play six balls (1).

For players with severe motor impairments such as cerebral palsy with quadriplegic involvement, an assistive device is necessary to advance the balls. An able-bodied assistant who may not face the playing area can also assist the athlete. The ramps or shoots are individually designed, but must adhere to some restrictions. It must fit into an area 1m x 2.5m when laid on it's side, it can not use any mechanical device to propel the ball, and can only use gravity as a means of propulsion (1). There are other minor details as to the ramifications of the ramp or shoot design. The ramp should be adjustable in such a way as to control the velocity the ball leaves the shoot at. Some ways velocity has been controlled are angle of inclination of the ramp, height the ball is released at, and a dampening mechanism which inhibits ball speed at some point along the ramp (2).

STATEMENT OF PROBLEM

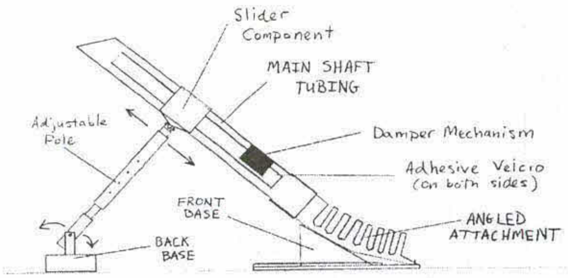
The purpose of this project was to design a ramp that could be used in competition and would improve upon the design of currently used ramps. The ramp was to be designed for the purpose of international competition abiding by the rules as declared by the International Paralympic Committee. It should be useable by park district/non-competitive athletes as well. The main problem with presently used ramps seemed to be lack of versatility. Many players are comfortable with one form of adjustability, referring to the way ball velocity is controlled and thus distance traveled by the ball, but not another form. Also, certain methods of controlling ball velocity, such as an assistant holding the ramp at a certain inclination, have a human error factor. The main goal of this project was to design a ramp that is easily adjustable. The ramp should have several methods of controlling shot distance, and it must eliminate as much human error as possible.

DESIGN & DEVELOPMENT

There are four major components to the device: 1) Front base with adjustable wedge support, 2) Angled attachment, 3) Main shaft tubing, 4) Back base with slider attachment. All four of the components add to the wide range of adjustability the ramp has. (Refer to attached figures 2-5 for more detailed drawings of individual components.)

The front base was the simplest to fabricate. Its purpose is to provide support to the flexible attachment and at the same time keep the unit from sliding forward. The wedge is adjustable to allow for support of the different angles of the flexible attachment. The protruding screw prevents the PVC portion of the device from sliding forward, and allows for a twisting action of the entire unit, which when held, adjusts the angle of release.

The best material for the angled attachment was determined to be PVC piping with 1in. segments removed. Other ideas for the attachment piece included bending a solid portion of PVC completely with heat, black corrugated drainage pipe, and a rigid 22.5° bend. After experimentation, the tube with segments removed allowed for the most flexibility, least resistance to ball travel, and most accurate direction of the ball. It is the key component to the adjustability of the entire unit. The piece is 30in. long with a 4in. insert to allow for attachment to the main shaft. There are 1in. segments removed from the remainder of the tube. These segments along with heating it supplied the desired bend.



Note: Figure Not to Scale

The main shaft has a bell end, which allows for the attachment to be easily inserted and removed. There are two Velcro pieces on each side, with a cut 28in. x 3in. made 6in. from the bottom of the tube to the front and center of it. The ball can be placed anywhere along this cut as a height adjustment, controlling ball velocity. A vinyl piece with Velcro dampens the ball speed at any point along the rectangular cut in the tube, allowing for velocity control.

The back base with slider attachment provides stabilization to the device while at the same time allows for height adjustment. The back base can be slid back or forward to control height. If the back base is held in place, the slider can be moved up and down the main tube to raise and lower the height of the tube. Also, in the back slider attachment is an adjustable pole which allows for 6 different height adjustments.

All of the components add to the adjustability of the system. To summarize, there are 6 different methods of ball velocity control:

1) Moving the back base forward or backward.
2) Adjusting the height of the adjustable pole.
3) Sliding the slider up and down the tube.
4) Positioning of the vinyl dampening mechanism which slows ball velocity at different heights.
5) Manual adjustment by disconnecting the device at front and back bases.
6) Placing the ball in the slot of the main shaft at varying heights.

EVALUATION

The device was used Saturday, September 18th, 1999 at an annual wheelchair athletic competition held in Skokie, IL, in which over 200 athletes participated. The device was used by several of the competitors participating in the boccia competition. According to Craig Culp, Superintendent of Recreation at the Maine-Niles Association of Special Recreation, it provided the necessary methods of adjustment for those who used the device. It was not used by as many athletes as would be hoped for because of lack of practice with the device before hand. However, Craig thinks that with more usage, it could become the preferred ramp used by several of his athletes.

DISCUSSION

With the growth of the wheelchair sport, boccia, there is a need to provide an easy means to compete for those who need assistance. Overcoming some of the main problems associated with the ramp used in competition (i.e. the methods of adjustment) was a main goal in the design of this device. The use this device has already been put through shows a lot of potential for it to diminish some of these adjustment problems. It provides various methods of adjustments, while eliminating a great deal of the human error associated with these adjustments.

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A Potato Wrapper for People with Limited Hand and Finger Coordination

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ABSRACT

Following the current trend to incorporate people with disabilities into society by giving them employment, so they may attain certain independency, a potato-wrapping device was developed. This article presents the process followed for the development of a device designed to help people with limited hand and finger coordination to wrap potatoes completely with tin foil. The goal of this device is to reduce the fine movements required by the user in the wrapping process. It also aims to improve the overall quality of the wrapped potatoes.

BACKGROUND

The device presented in this paper was originally designed for a person who suffers from cerebral palsy, which limits the fine coordination of movements like hand-finger dexterity and usage of both hands. As part of her school program with a restaurant, she is required to wrap potatoes with aluminum foil. Due to her disabilities she is not able to wrap potatoes properly, which requires fine hand/finger coordination. The basic process of wrapping consists of positioning the potato over the tin laid tin foil, and folding the foil around the potato's contour to cover it completely.

SYNTHESIS

Once the problem was identified, the need for a design methodology to help the customer had great importance to produce the best results. The steps followed for reaching the solution of the problem are:

1. Customer's needs analysis.
2. Concept development.
3. Embodiment design and prototyping.

Customer's Needs

The main customer needs identified by conducting interviews, focus groups, and literature search, were:

- Quality of Wrapping
- Adaptability to different users
- Safety
- Simplicity (of design, and operation of device)
- Portability
- Ergonomics (manual operation by person with disabilities)
- Durability
- Cost
- Number of operations done by user
- Standard parts utilization

The customer's needs were transformed into target specs through the Quality Function Deployment matrix (QFD) [1,3].

Concept Development

In the concept development stage, the main functions of the wrapping process were identified based on customer's needs. The solutions for every function identified were generated through brainstorming [1,2]. These solutions were combined to get five overall concepts of the device. After carefully evaluating each of them, the present concept was selected (fig. 1).

Embodiment design and prototyping

The next phase that was carried out was the embodiment design of the device [1,2]. In this stage the main tasks dealt with were:

1. Dimensions of the device (geometry and layout)
2. Component interfaces
3. Materials
4. Optimizing design parameters to reduce the operation effort
5. Quality and manufacturability

After the first embodiment stage, the first physical prototype was developed. Feedback from the customers was obtained. The main design parameters identified are the following (see fig. 1):

a) Profile of the cam.
b) Height of the back plate.
c) Height of the bottom cushion.
d) Distance between the two side cushions.

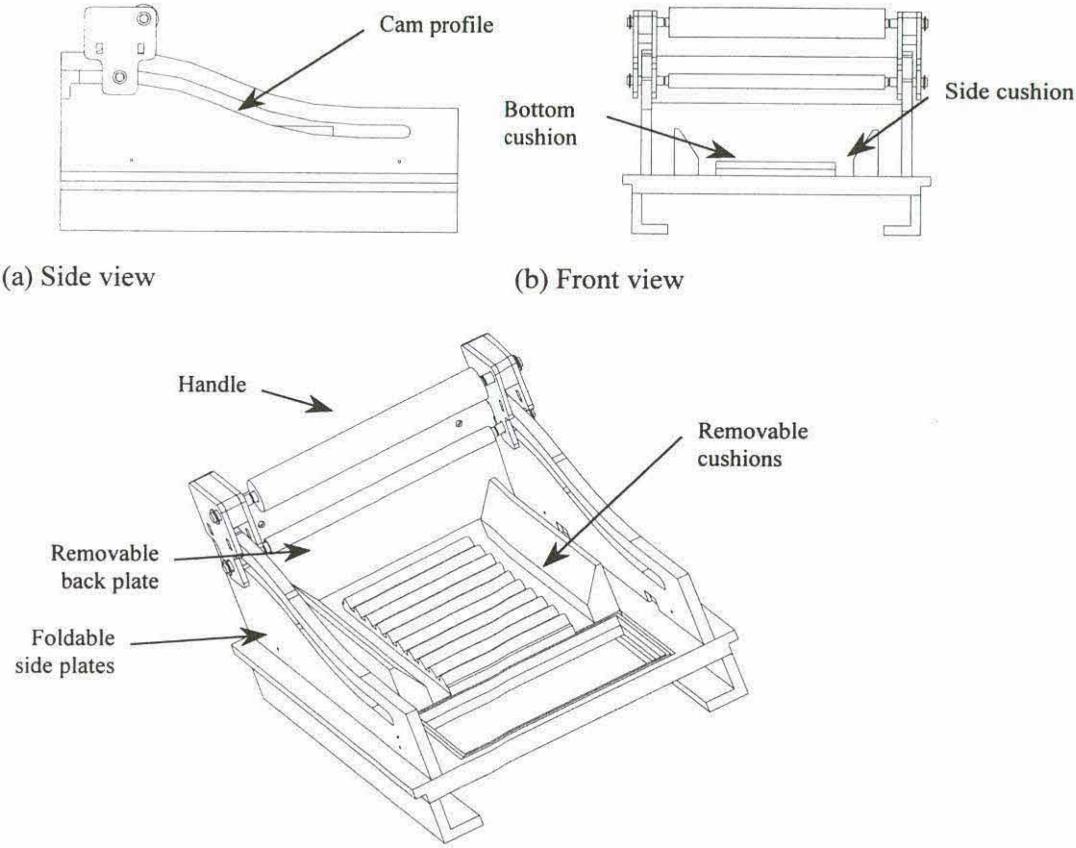
A series of experiments with respect to the above parameters were then performed to optimize the effort required by our customer to operate the device the above parameters using Design of Experiments (DOE) [1]. The optimized parameters were implemented into a final prototype, which was given to the customer.

KEY FEATURES OF THE DEVICE

The key features of the device are outlined below (see fig. 1 for details).

1. ***Profile*** : The profile guides the handle so the cloth can cover and compress the foil around the potato and roll to the exit.
2. ***Base cushion and Stretchable Cloth*** : These act together to tightly form the foil along the potato's contour and also relieve the actuation effort.
3. ***Side Cushions*** : These cushions along with the above features compensate for the folding of the foil around the ends of the potato.
4. ***Disassembly features*** : The following features were incorporated into the device for storage, portability and cleaning reasons. These are:

- Foldable side plates
- Removable back plate
- Removable cushions and cloth (not shown)
- Removable handle assembly



(c) Isometric view

Figure 1. Implemented concept for the potato-wrapping device.

By implementing the above key features, we were able to create a device that reduces the wrapping process effort, and achieves a good quality outcome. We provided our customer with a satisfactory design, which was not available in the market.

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4-BAR LINKAGE MECHANISM FOR CHILD PREHENSORS

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ABSTRACT

Prehensors for young children (ages 1-5 years) often have insufficient gripping capabilities related to gripping patterns and gripping sizes[1]. Our design provides a mechanism which can replace the usual scissors-like mechanism of prehensors and provide more usable gripping patterns for a larger range of shapes and sizes to be securely gripped by children.

BACKGROUND

Two major problems exist with current prehensors used by young children between the ages of one and five years of age. First, prehensors are not mass-produced, because of this, these devices are expensive. Our goal was to design a prehensor that would be low in price but provide better performance. Second, a performance problem which exists is that some prehensors do not provide adequate gripping patterns for large or circular objects. This problem is common for prehensors with single hinge mechanisms, such as hooks. The problem with the single pivot scissors-like mechanism is that only two points hold the object and the forces acting on the object have the tendency to push the object out of the prehensor.

PURPOSE

The purpose of our project is to design a prehensor for children ranging from one to five years of age. The prehensor should be simple to manufacture, inexpensive, and moreover is able to solve the problem which exists with the single hinge prehensors, while having acceptable appearance.

METHODOLOGY

For every design there are specifications and constraints to be met. We decided that our prehensor should be voluntarily opened (pulled to open) and self-closing. To open the prehensor the user stretches his/her hand forward, which pulls on the cable allowing an opening, while the springs in the prehensor provide the gripping force. The constraints such as the displacement, and the force children can provide on the cable was estimated based on expert consultation.[2] Obviously these numbers vary from one child to another. Our gripper was designed so it will hold as large an object as possible, provide as much gripping force as possible, without underestimating other constraints such as the price, simplicity, durability and the appearance of the prehensor.

During the period of considering different ideas we were advised to use the shape of the Child Amputee Prosthetic Program (CAPP) prehensor and come up with a better gripping mechanism since the CAPP is popular for the target age group. We attempted to design a mechanism that will fit within the shell of the CAPP prehensor, which would provide a better gripping pattern.

FINAL DESIGN

After considering several mechanisms we selected one with a single degree of freedom. This way we could analyze the mechanism on paper before building a prototype. The final design consists of two 4 - bar linkages coupled by two gears (Figure 1).

Figure 1 The final mechanism. Two 4-bar linkages coupled by two gears

We felt that this mechanism would be simple to make and fairly rugged. All the parts are similar and have simple shapes so they can be easy and inexpensive to manufactured. The other components, such as the gears, shafts and springs are standard parts that are readily available.

ANALYSIS

The next step was to define the dimension of the members, and the location of the joints and shafts. It was obvious that the design of our mechanisms will be iterative process. The easiest and the fastest way to go through the iterations was to write a Mathcad program to calculate the motion of the mechanism relative to the shell. We wrote a program, which could compare the motion of the mechanism to the trace of the shell. The lengths of the members, the location of the joints, and the size of the gears were variables with which we experimented.

After deciding on the dimensions of the members and the positions of the pivot points the next step was to determine the gripping force, the forces in the members, and the force required to operate the prehensor. The closing force would be provided by two torsion springs located on the shafts of the gears. To make the calculations efficient, the Mathcad program was modified to calculate the forces at any point in the motion of the mechanism.

We had to decide how to drive the mechanism and how much force was required. Figure 1 shows the two concentric pulleys used as the driving mechanism. The cable was not attached to the top linkage for direct drive. This was based on our understanding that a child can provide about two inches of displacement on the cable, but the joint where the cable is attached, moves only 0.4 inches. If we directly drove the mechanism then we would be wasting the remaining displacement that could have been used. Therefore, by using the pulleys we could increase the displacement and reduce the input force, by the ratio of the two pulleys. By doing this we could use stiffer springs in order to produce more gripping force while making the gripper easy to operate.

RESULTS

We built a prototype for testing with a patient. The test was scheduled for the Child Amputee Prosthetic Program (CAPP) at Shriner's Hospital for Children, Los Angeles. Prior to arriving to the hospital, we did not know about our patient, therefore soft springs were installed in the prototype so that even a weaker subject would be strong enough to use the prehensor.

Once the patient started using the gripper it was apparent that she did not have a lot of trouble using our prehensor because its operation is almost similar to the original CAPP prehensor. The occupational therapist asked the patient to perform several tasks to test the pattern of our gripper in different situations. During the test the patient was asked to grab rectangular, cylindrical and random shapes. She was even asked to hold a piece of paper in the gripper and use scissors to cut the paper. Figures 2 are pictures from the testing, and each shows the patient handling different shape objects.

Figure 2 Pictures taken during the testing.

The patient was able to successfully complete all of the tasks that were given to her. She was able to hold paint and glue battles and open them. She was able to hold rectangular objects, such as boxes with good security. The gripper also held sheets of paper very securely when she was using the scissors. During testing there were five professionals present, therapists and prosthetist and all of them had a positive reaction for our design.

CONCLUSION

Our prototype can handle objects about 2 inches in diameter. The original CAPP mechanism can open up to 3 inches but the larger it opens the less secure the grip becomes. But in our design the gripping pattern remains the same through the whole range of motion. The motion of the mechanism fits nicely in the shell of the CAPP, and functioned as predicted on paper. When we tested the prototype the patient started using the gripper without any trouble. This is a big advantage because the patients do not have to go through a training period in order to use our device.

We unexpectedly found that our design has an easy-feed feature. Easy-feed is a term coined by the Rancho Rehabilitation Engineering Program. It means that the user does not have to pull on the cable in order to insert an object into the prehensor.[3] By pressing an object against the bottom gripping surface, the prehensor easily opens and the object can be inserted. Our recent finding of the easy-feed feature alone has potential for improving the functionality of our prehensor design.

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SWITCH ACTIVATED BALL THROWER

Matthew Green, Clark Anderson, Chris Nguyen, and Shariq Samad

ABSTRACT

Occupational therapists often work to integrate children with disabilities into normal classroom activities. Gym activities that involve ball-throwing games pose a difficult challenge for children with mobility impairments. A mobile, switch-activated ball thrower has been designed and prototyped to facilitate the inclusion of children with mobility impairments into ball throwing activities. The device is adaptable to a variety of games, easy to use, and economical to reproduce.

BACKGROUND AND PROBLEM STATEMENT

This project started in response to a request from an occupational therapist who works with elementary school students with mobility impairments. She wanted to include her students in playing games with their classmates during gym time. Many of these games focus on ball throwing: basketball, dodge ball, and tossing games. Her vision was for a portable, simple device that could easily be moved alongside the child's wheelchair. She wanted the device to interface with the remote "big mac" switches the children were already familiar with. Since no device on the market fulfilled these requests, there was a need for the design of a new device. The purpose of this project was to design and build a switch activated ball thrower ball thrower that was adaptable to a variety of games, easy to use, and economical to reproduce.

DESIGN METHODOLOGY

Gathering Customer Needs

The first phase of this project focused on understanding the needs of the children and teachers who would use the device. The goal was to discover "what" the customers really needed with an open mind without becoming pre-maturely locked into design solutions. The design team spent time with local schools gathering this information. A focus group was conducted in a round table format that allowed teachers and therapists to share their vision for the project. Observation and interaction with the children who would use the ball thrower revealed unspoken needs. The customer needs were prioritized, measured with House of Quality techniques, and then used as the basis for generating design concepts (1).

Concept Generation

The next phase of the project involved generating concepts to fulfill the customer needs. The problem statement was decomposed into sub-problems corresponding to functions that the device needed to perform. For example, the problems of holding the ball, triggering, and aiming were at first each considered independently. Ideas were generated using traditional brainstorming methods as well as newer idea generation techniques such as brain writing (1). Approximately sixty solution variants were identified. These partial solutions were then synthesized into design concepts. A sketch of one

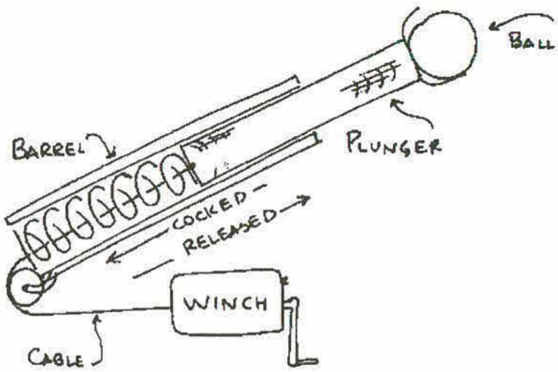

Figure 1: Compression Spring Concept

of these concepts is shown in Figure 1. The most promising of these design concepts were next evaluated during the concept selection phase.

Concept Selection

The concept generation phase resulted in four viable concepts that were considered for development: a catapult mechanism, rotating wheels, a slingshot device, and a compression spring concept. Several decision-making criteria were used to rank the concepts and select the most feasible one for development. The safety of students and therapists was of primary concern. Low maintenance was another customer need, which suggested that a simple design was preferable. The device needed to be economical to re-manufacture if it was to have widespread use. A subjective evaluation of the design's ability to capture the interest of students and teachers was also considered. This was dubbed the "Wow!" factor since it measured how likely the user was to have a positive first impression of the device. Based on these evaluation criteria, the compression spring concept (Figure 1) was selected to proceed with design and development. This selection was made based on the prediction that this concept could best fulfill the customer's needs.

DESIGN & DEVELOPMENT

The next phase involved developing the sketch of the selected concept into a working prototype. The decisions made during this stage were driven by the customer needs. Designing a safe device was a first priority. In order to score a basket from the free throw line, a basketball must leave the barrel at 20 miles per hour. This requires high forces and energy storage within the ball thrower. Therefore it was important to choose a design that adequately insulated the users from moving components. A five-gallon polymer bucket was selected to hold the ball in place and insulate the users from moving parts. A bucket was an economical choice that worked well. This is one example of a number of design decisions made to keep the device as simple and economical as possible.

To enable the teacher to cock the device, a winch and cable arrangement was chosen to store energy in the compression spring (Figure 2). One advantage of this system is that it allows multiple power settings since the cranking distance controls how far the ball will shoot. A decision was made between a winch with a clutch ($125) and a normal winch ($20). The less expensive winch had the disadvantage that its handle would spin while the winch was being unwound during the release of the ball. The less expensive winch was chosen for economic reasons, and an electronic interlock was installed as a safety so that the device could not be fired until the user removed the winch handle.

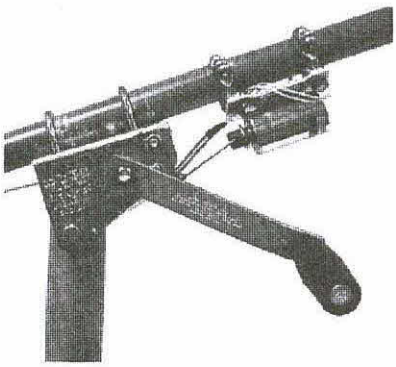

Figure 2: Winch Mounted to Barrel

In order to make the ball thrower mobile, a rolling cart was chosen with wheel brakes. This allows the ball thrower to be mobile or stationary depending upon whether the brakes are set. Along with a variable shooting range, the device has a range of angle settings. It can be swiveled around to shoot in any direction without moving the cart. The ball thrower can also be aimed at any angle from horizontal to straight up.

EVALUATION & DISCUSSION

The children who first tested the device and the OT who requested it both enthusiastically received the ball thrower (Figure 3). It succeeded in meeting the design goals of being adaptable to a variety of ball games, easy to use, and economical to re-build. The device is adaptable to a variety of ball games due to its wide range of aiming angles and multiple power settings. At maximum power, the ball thrower will shoot a regulation size basketball up to 35 feet. It can also be used to gently toss a soft ball to a nearby classmate. The teacher can easily set the device to aim horizontally, vertically, or at any angle in between. It will also swivel 360 degrees for a wide target area. The ball thrower is mounted on a cart equipped with wheel locks. This allows it to be positioned securely in one location, or rapidly moved during gym activities.

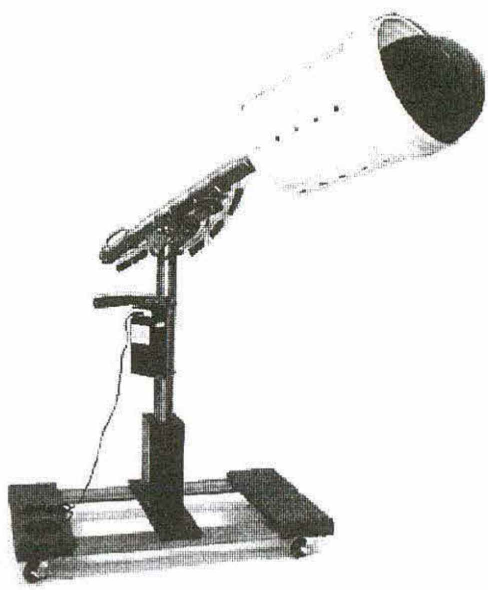

Figure 3: Complete Ball Thrower

The ball thrower is also easy to use. An off-the-shelf winch allows the teacher to cock it by winding it three or four times. The winding force required is less than 10 pounds, a value consistent with accepted ergonomic standards (2). The child may use any remote switch with a standard 1/8" plug to trigger the device. Once the device is cocked and the switch plugged in, the child may fire at will by pressing the switch. A pair of long-lasting rechargeable batteries powers the ball thrower. The batteries used are calculated to last at least one month before needing recharging. A battery charger provided with the ball thrower can be plugged into recharging jacks mounted on the device so that the teacher does not have to handle the batteries. Due to lightweight construction, the complete ball thrower weighs less than 30 pounds. The device also disassembles into two parts within seconds to fit easily in a storage closet or a standard size car trunk.

Great care was taken during the project to insure that the device could be re-manufactured for other schools. Off-the-shelf parts were used whenever possible to avoid the costs of custom manufacturing. When the design was complete a detailed bill of materials was compiled along with exploded views to aid in duplication the device. As testimony to the success of the project, another occupational therapist has already requested a duplicate of the ball thrower after witnessing a demonstration.

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DESIGN OF PERSONAL AUGMENTATION DEVICES (PADs): EXPLORATORY PLAY AGENTS FOR CHILDREN WITH SEVERE DISABILITIES

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ABSTRACT

Prototype personal augmentation devices (PADs) were developed as exploratory agents to enable tele-interaction, evaluation, and development of abilities in children with severe disabilities. The system consists of a custom-built data acquisition box, HCI software and remote controlled car and Nintendo interfaces.

BACKGROUND

Play has long been considered one of the most important aspects of a child's life, and has been used as a tool for developing a child's natural medium of expression where the child becomes more sure of him/herself (1). Establishment of a link between play materials and social cognitive development has been attempted, observing that motivation, brought about by objects such as toys, that bring about challenge and control, can facilitate this development (2). The use of robotics has presented itself with a different approach to rehabilitation and education, where the device can represent an extention of oneself to replace lost function (3). Computer-based systems, such as NeatTools (NT), have the potential for being universal and modular, as the functionality, power, and affordability continues to improve (4). NT was developed as a visual based run-time program, and uses blocks of functions called modules that allows the user to quickly link several I/O peripherals using ready or custom created modules. Coupling the power of computers to simple, inexpensive sensor and interface technologies, a variety of options become available through computer-control of many external devices such as a remote-controlled car or a game system.

PROBLEM STATEMENT

To enable children with severe disabilities to derive the same benefits of play, we need to break down the concept of play into two parts. Control over one's environment and exploration of and interaction with one's environment. We needed to develop PADs to instrument a child and then enable them to "tele-interact" with their environment through an exploratory agent. Finally, this has to be accomplished inexpensively.

RATIONALE

Cognitive development is considered to be strongly dependent on learning through observation and direct manipulation of one ' s environment. PADs are devices that can navigate and manipulate the external environment under the control of a child with a severe motor disability. The impact of this system is to provide an exploratory agent for the child that allows the child to tele-interact, thereby unlocking his/her cognitive abilities; promoting curiosity and a sense of entitlement to explore; and allowing development to continue.

DESIGN

The main design objective is to solve the problem statement, and to do so in a user (patient/therapist/engineer) centered design, based on the HCI development environment of NT. Figure 1 shows the system interface schematic, that became the cornerstone of the design process.

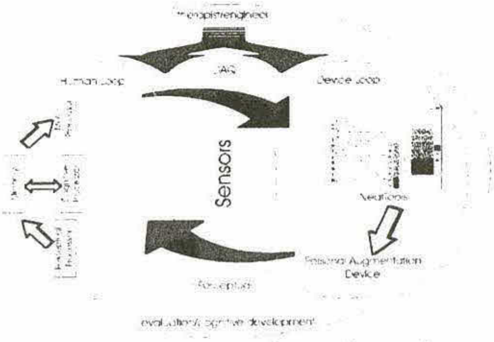

Figure 1: System interface schematic

There are two main loops, the Human and Device loops. The Human loop represents learning and processing models of the mind, which need to be interfaced through play. The body then interfaces to the device loop through sensors, specifically through a Data AcQuisition unit (DAQ). The device loop consists of a computer, with the NeatTools (NT) software package which performs the main processing, and PADs devices. Human perception/ stimulation then is used as the sensors, to complete the feedback loop. The design is focused on the interfaces between the two main loops.

Secondary design objectives include low-cost, ability for rapid-prototyping, and adaptable, upward compatibility. Robotics and input devices for Assistive Technology (AT) applications, tend to be expensive. Low-cost is a very important objective and will be accomplished using consumer electronics, meaning that typical interfaces will be able to be assembled without a vast knowledge of electronics and specialized tools. Rapid-prototyping will come into play when the ideal set of inputs for a given disability is yet unclear. In this situation the ability to swap inputs (specified later) and to configure the optimal system efficiently proves to be an asset. Upward compatibility refers to providing sufficient design liniency to being able to accommodate the development of any future sensors to the DAQ unit without modifying the unit itself. These objectives are incorporated into the designs of the input and ouput interfacing hardware.

Input: Since the system is designed to incorporate uses for a variety of disabilities, it is necessary to make the sensors as versatile as possible. The resolution and sampling rate of the DAQ needs to be sufficient for low resolution metrics. The design will use one microcontroller to handle analog to digital conversion (ADC). The serial port will be used for computer interfacing.

Output: Output is interfaced from the computer through the parallel port, and is currently used as simply digital on/off. The control of the device will be adaptable to the needs of the patient, giving the therapist maximum control over the activity. Interfacing is made to off the shelf remote controlled (RC) cars and a Super Nintendo game system.

DEVELOPMENT

The software was designed in a general I/O configuration. The input data is specified from the serial port, the raw data is then run through some general processing, and a threshold setting is applied to directly trigger on/off parallel port pins.

Input: The DAQ is designed around a microcontroller, PIC16C74. The micro performs the ADC and serial port communications. The unit accepts 8 channels of analog, and is sampled at 200Hz with 8 bits of resolution. It can be powered 3 ways: directly from the serial port, from 9v battery, or from the PS/2 (keyboard port) of the computer. The two latter options have the ability to supply more power and a negative voltage via a switch. The sensors plug into the unit using a modular (phone) jack, which has 4 contacts (-5v, +5v, analog in, ground). Two levels of sensors were developed. A series of passive sensors that act like potentiometers and a series of active sensors that require extra power from the unit. The passive sensors used were rotary and sliding potentiometers, measuring rotation or displacement; force sensitive resistor pressure sensors; resistive bend sensors that measure deflection and cadmium sulfide photo cells used as pseudo-proximity sensors. The active sensors developed so far are an accelerometer, a Biometrics goniometer and two EMG designs. The dual axis accelerometer is primarily used as a tilt sensor, and the Biometrics is a very convinient dual axis goniometer. Both are high resolution and highly accurate but are more expensive. The two EMG designs have RMS and frequency counting abilities. Other inputs worth mentioning are generic computer inputs that are used everyday such as joysticks and the mouse.

Output: Two devices were adapted to be used with the PADS system, an RC car and a Super Nintendo game system. Both are connected to the parallel port of the computer, and use transistor or optoisolator circuits for interface. Also, a speed selector switch was added to the car that allows for slow/ medium/ fast speeds of the car.

EVALUATION

Developing prototypes of exploratory agents was inherently a user-centered design process. We worked with 4 children, and therapists for our needs assessment and included these children in the design process. They showed enthusiasm for the devices as therapy as well as an evaluation tool.

To demonstrate the system, a 'Technology Day' was set up, (8) children came to experience the different interfaces. A questionaire was made to assess the reactions of the children and the parents. The overwhelming consensus was that the RC cars and Nintendo systems, setup for both interfacing and rehabilitation excercises, were equipment that they would like to use at home.

DISCUSSION

The design objectives were met. The passive sensors, RC car and Nintendo game systems are inexpensive and allow the use of inexpensive parts and toys available at local stores. The advanced sensors are more expensive but give the system expanded capability, providing a framework for the upward compatitbility. Rapid-prototyping is facilitated by the software and interactivity of all the components, with the ability of them to work together within different configurations.

Three areas of development 1) to conduct more quantitative studies to study the effects of the system within the play and rehabilitation settings 2) incorporate remote monitoring capabilities to allow therapists the ability to monitor/advise progress and 3) more advanced exploratory agents will be developed to increase the functionality and challenges.

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Sixth Annual
Research Symposium

Ergonomics:
Emerging Technology to Increase Participation in Education, Employment, and Independent Living – Making Engineering Technologies Work!

PAPERS FROM THE RESNA 2000 ANNUAL CONFERENCE RESEARCH SYMPOSIUM ERGONOMICS: AN EMERGING TECHNOLOGY FOR INCREASING PARTICIPATION IN WORK AND DAILY LIVING

Thomas J. Armstrong, Ph.D.
2000 Research Symposium Organizer
University of Michigan Rehabilitation Engineering Research Center: Ergonomic Solutions

At a global level, engineering technologies have resulted in productivity levels well beyond those of manual work methods, and for many, a standard of living that is the highest in human history. Yet some individuals have not achieved this standard of living by virtue of their mental or physical condition. Engineering technologies have great potential for enabling people with special needs to participate in routine activities of work, daily living, education and recreation, yet these technologies are not always applied or if they are, they do not always work. In many cases related to work environments, these failures can be attributed to not fully considering the work requirements or the workers' abilities.

Ergonomics is an emerging technology concerned with 1) understanding and predicting human work "capacities," 2) developing models for analyzing and describing task "demands" and 3) applying these models to achieve compatibility in the design of interactive systems of people, machines and environments. Ergonomics is concerned with enabling all people regardless of age, sex and ability level to freely participate in activities that are productive, safe, healthful and promote a sense of well-being. Ergonomics draws on basic sciences such as psychology and physiology, and utilizes mathematics, statistics and computers to develop engineering models that can be used for analysis and design of work equipment and activities.

The RESNA 2000 Annual Conference Research Symposium brings together leading researchers who are engaged in developing ergonomic models and methods. Papers describing their work follow. The first group of papers are concerned with physical anthropometry and biomechanics, the second group with the psychological aspects of work, the third group with procedures for analyzing work equipment and procedures and the last group with population studies of ergonomic factors and worker well-being.

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BIOMECHANICS OF MOBILITY AND FALL-ARRESTS IN OLDER ADULTS

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ABSTRACT

Mobility problems are common among the elderly. Falls, when they involve injuries, can result in serious mobility impairments. Some of these fall-related injuries may be preventable with better educational and physical interventions. Although age can reduce some physical and cognitive capacities, most activities of daily living do not require substantial capacities to be utilized, especially if the individual is able to modify the task demands. Thus age-related changes do not usually cause difficulties with easy tasks because their demands are low and capacities suffice. As we shall see, age-related changes usually cause difficulties with more challenging physical tasks, such as attempting recovery from a fall.

PREVALENCE OF MOBILITY PROBLEMS

It has been estimated that more than 20% of the population of the United States will be aged 65 years or older by the year 2020 (1). Indeed people who live to 65 years of age can now expect to live into their eighties (2), and eighty-year olds are the fastest growing segment of the older population. While people 65 years and older have 16.4 years of life remaining on average, they have about 12 years of healthy life remaining (2,3). So maintaining, and even improving, functional independence during these years should be an important socioeconomic goal. Unfortunately, among non-institutionalized persons 65 years and older, approximately 13 percent have difficulty performing activities of daily living. Approximately 9 percent have difficulty bathing; 8 per cent have difficulty walking; and 6 percent have difficulty with bed or chair transfers. These rates rise with age, so that more than 34 percent of non-institutionalized persons over the age of 85 years have mobility problems.

FALL-RELATED INJURIES

One of the greatest threats to independent functioning in the elderly is a fall. Older adults have an increasing tendency to fall and be injured by falls. For example, approximately one-third of community-dwelling elderly fall each year (4,5). About one in twenty of those who fall will fracture a bone or experience significant injury requiring hospitalization. Wrist fractures are more common under the age of 75 years, while hip fractures become more common over that age. The 300,000 hip fractures that occur every year in the United States have been estimated to cost approximately $7 billion (13). Ninety percent of these injuries are the result of a fall. The causes of falls are not presently well understood. Risk factors for falls include increasing age, female gender, alchohol consumption, relative weight, heavy physical activity during leisure time, environmental factors, poor vision, declines in lower extremity strength, peripheral neuropathy, impaired balance, previous stroke, dizziness, impaired cognition, and polypharmacy (see, for example, 6). The risk for falls is known to increase when multiple risk factors are present. In a one-year study of 1,042 persons greater than 65 years of age, tripping was reported to be the cause of the fall in 53 percent of the 356 falls that were documented (7). Whatever the underlying neurological and physiological mechanisms that cause a trip, responses to a trip are ultimately expressed in biomechanical factors.

AGE-CHANGES IN SELECTED SENSORY AND MOTOR CAPACITIES

In this section we examine the effects of age on some of the physical capacities that determine the effectiveness of a biomechanical response to a trip.

Proprioception: Proprioception is the awareness of body segment position and orientation. The threshold for detecting motion at a joint in the lower extremities, without the aid of vision, is on the order of tenths of a degree, and is speed sensitive (for example, 8, 9). These same studies show that age significantly degrades these thresholds, but only to a minor degree. The threshold for the reliable detection of foot rotation is 10 times smaller under weight-bearing conditions than under non-weight-bearing conditions (see, for example, 10). Importantly, peripheral neuropathy leads to a 4.6-fold increase in these thresholds (11). Peripheral neuropathy has been shown to be associated with a 23-fold increased risk of falls, and a 6-fold increased risk of fractures (12). If ever there is a group of older adults who need to be warned about their increased risk for fall-related injuries, it is patients with peripheral neuropathy.

Reaction times: Reaction times have been defined in many different ways, complicating comparisons of different studies. In general, they are defined as the delay between the onset of the stimulus and the onset of the response. But even for the same stimulus, differences in reaction times will arise depending upon whether one considers the onset of myolectric activity, the onset of a change in reaction force under a limb, the onset of acceleration of that limb, movement of the limb to a certain target, or even depression of a switch following the limb movement. Movement times will of course depend on the distance to be moved. In addition, the more choices a subject has in responding to a cue, the more reaction time will slow. If there is no choice then this becomes what is known as a simple reaction time task. If there are multiple choices, then choice reaction time depends upon the logarithm of the number of choices to be made. Choice reaction times are therefore considerably longer than simple reaction times. Speed-accuracy tradeoffs are also found in reaction time measurements for Fitt's law holds that reaction time increases with greater accuracy demands. Many studies report significant age differences, but not gender differences, in reaction times among healthy individuals. Myoelectric latencies are typically 10 to 20 msec longer in healthy 70-year olds than in healthy 20-year olds in simple reaction time experiments. Since a fall to the ground usually takes about 700 msec (13), such minor delays are usually considered to be inconsequential.

Muscle contractility: Loss of strength occurs with age even in healthy older adults. By the age of 65 years, maximum isometric strengths have decreased by approximately one-third. In addition, the maximum strengths of females are about one-third less than male controls of the same age, although their strength-to-weight ratios may be similar. Research in the last decade has uncovered significant age-related slowing in the maximum rates at which muscles can generate tension. In one study, for example, the mean time it took healthy older females to develop 60 Nm of plantarflexion torque was 472 msec as compared to 311 msec in healthy 20-year old young females (14). This delay of 161 msec was 52 percent longer than the young, and it far outweighs any 10-25 msec age-related slowing in myoelectric latency difference (15). Corresponding times for males were 313 and 270 msec, respectively, showing similar trends. This difference in the rate at which muscle can develop tension cannot be explained in terms of muscle recruitment differences (15), suggesting that it is mainly due to a change in the contractility of the muscle itself. This reduction in the capacity of muscle to develop tension under emergency conditions, such as those underlying a fall response, should adversely affect the maximum acceleration with which the elderly can accelerate their limb in order to say, take a rapid step in order to arrest an ongoing fall. In fact, we shall see that significant and profound age differences have been found in fall arrest capabilities during forward falls (16, 17). Rapid movements may also require maximal power output to be developed about a joint in order to maximize the velocity of the body segment to a target location. Measurements of human power output capabilities have shown reductions with age of 3 percent per year for men, and 1.7 percent per year for women over the age of 65 years of age (for example, 18, 19). So, the ability of the elderly to reach joint angular velocities over several hundred degrees/sec is likely limited.

Elderly muscle retains the potential to hypertrophy by up to 49% and 163% in the arm and leg, respectively, when trained using heavy resistance training (85% of one-repetition maximum) over an 11 week period (for example, 20). Life-long endurance training, however, is of little value in maintaining muscle strength and speed of contraction in old age (21).

It seems clear that few exercise interventions that have been undertaken to prevent falls in the elderly have emphasized agility in terms of developing muscle force as quickly as possible, or of improving power output at high angular velocities. The biomechanical studies of the last decade to be reviewed next suggest that future interventions might consider such variables.

GAIT AND TRANSFER TASKS

In the absence of disease, comfortable gait speed of 1.3-1.5 m/sec is unaffected by age until the age of 60 years, after which it declines, on average, 1 to 2 percent per decade through age 80 years (for example, 22,23). Sarcopenia, an age-related loss in muscle mass, is thought to cause a diminution in physical functioning. In general, loss of muscle strength does correlate with loss of gait speed, however, a non-linear relationship between lower extremity strength and gait speed has been noted (24). This relationship indicates that there exists a threshold of lower extremity strength above which strength must be maintained in order to maintain comfortable gait speed. When strengths fall below this value, as frequently happens in the frail elderly, then small decreases in strength can have a marked deleterious outcome on gait speed. Gait speeds below 0.5 m/sec are regarded as a sign of frailty. On the other hand, the non-linear relationship also means that interventions that lead to small increases in strength in the frail elderly can have a beneficial effect on improving gait speed. Among the frail, lower extremity strength has also been found to be an important predictor of performance on standardized tests of postural balance and rising from a chair (for example, 25, 26).

EFFECT OF AGE ON OBSTACLE AVOIDANCE

Obstacle Avoidance: Given that trips are a major cause of falls at any age, the ability to reliably avoid an obstacle in the gait path is an important aspect of mobility. Somewhat surprisingly, my colleagues and I have found no effects of age on the toe clearance afforded an obstacle; older subjects did not afford an obstacle any more or less clearance than young subjects did (27). When we titrated the available response time required for healthy young and elderly to step over an obstacle which came suddenly to their attention, we found that healthy 70-year olds only required 30 msec longer than healthy 20-year olds in order to enjoy the same success rate in avoiding the obstacle (28). However, out of forty subjects three older adults and one young adult inadvertently fell when trying to rearrange their stride pattern in order to avoid the virtual obstacle on a flat level surface (29). Their safety was ensured by a ceiling-mounted safety harness. However, this experiment shows that even healthy adults can fall on a perfectly flat surface if they perceive an obstacle to be present, whether because of differences in lighting or floor surface coloring. Nursing home architects might take note of this finding.

Effect of Age on Dividing Attention: In life, we seldom focus on only one task at a time. Instead, we often multitask, dividing our attention between two or more tasks or processes. Thus, for example, we might be walking down a sidewalk when we see an obstacle we need to step over, but we may be distracted from doing so while talking with a friend, looking for a street sign, or simply thinking about a pressing problem This is an example of a divided attention task: avoiding the obstacle while also performing the second task. It has been shown that age adversely affects the reliability with which a healthy adult can step over an obstacle in the gait path, while simultaneously performing a visual search task (30). The neuropsychological predictors of performance on this divided attention task have been explored (31), and factors such as problem-solving ability and mental flexibility, along with psychomotor speed and attention have proved important. Divided attention may well be responsible for many injuries, both in industry at any age, as well as in the elderly. However, epidemiological data do not yet tell us how large this problem really is, except for the well known studies documenting the role of cell phone use in causing motor vehicle accidents.

Sudden Stops and Turns: Abilities to stop and or turn suddenly while walking are needed to avoid unseen objects or obstacles. An example would be avoiding a moving vehicle that suddenly encroaches on a cross-walk. If a large object suddenly comes to attention 1 m ahead while walking at a comfortable gait speed, then as much as 750 msec is needed to either stop or turn away from it (32-34). The physical challenge is to arrest one's forward momentum as quickly as possible, without losing one's balance. This is a 'time-critical' task that requires considerable coordination of body segments.

Fall Arrest Responses: Once a fall is initiated then it may be arrested by grabbing a support with the hands, using the hands to break the fall in a fall to the ground, or by taking a quick step in the appropriate direction. My colleagues and I have conducted several studies on the effect of age on the ability to arrest a forward fall with a rapid step (16, 17). In these tests subjects were leaned forward like a broomstick, suddenly released after a random delay, and instructed to arrest the ensuing forward fall using a single step. If they succeeded, then the forward lean angle was incrementally increased, and they again attempted a recovery with a single step. The results showed that healthy young males can recover from a forward lean angle of 32.5 degrees, while healthy 70-year olds can recover from a mean angle of 23.9 degrees, a significantly smaller angle. Healthy young females could recover from a mean lean angle of 30.7 degrees, while healthy 70-year old females could recover from an angle of 16.2 degrees. Five of the ten older females could not recover from the smallest lean angle of 13 degrees. Maximum lean angles correlated well with the average forward step velocity, and inversely correlated with the time taken to unload the stepping foot. Studies of myoelectric activities in 12 lower extremity muscles did not find a significant age difference in the shortest muscle latencies, which ranged from 73 to 114 msec, following release (35). Older adults were, however, slower to deactivate three stance leg muscles, and also demonstrated delays in activating step leg flexors and knee extensors prior to and during the swing phase. In summary, these results suggest that the age effects in the ability to recover from a forward fall result from an inability to move the leg segments rapidly enough, rather than from a delayed initiation of the response. This has implications for designing exercise interventions for the elderly.

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ANTHROPOMETRY FOR PERSONS WITH DISABILITIES: NEEDS IN THE TWENTY-FIRST CENTURY

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ABSTRACT

Anthropometry, the study of human dimensions, is useful for product and workspace design. Anthropometric data for people with disabilities is largely fragmented and difficult to use. We assess the current state of anthropometric research on people with disabilities and identify where the resources fall short of the needs. We outline a program for addressing those needs.

INTRODUCTION

Anthropometry, the study of human dimensions, has many uses in design. Since its ascendancy in the period following World War II, engineering anthropometry has been used to aid in the design of aircraft cockpits, automobile interiors, office and factory workstations, as well as homes and public buildings. What unites that list of domains is that they are all workspace dimensions – a place that the human must fit into. Anthropometry can also be used to aid in the design of products which fit onto the wearer. Examples include general clothing, protective clothing, helmets of many types, gloves, masks, shoes, boots and so on.

The design of products to fit onto the wearer is often characterized by sizing. That is, a bicycle helmet may be available in three sizes. Yet the design of workspaces, including all those domains listed above, are generally not sized; all human diversity is to be accommodated with only one size. There is one height for a doorway; there is one height for a counter in the kitchen. There is often one place from which the assembly-line worker must reach his part or her tool. Some workspaces are adjustable. One can think of so-called ergonomic office seating, or the 6-way power seat found in many automobiles. Newer factories have adjustable workstations, even on the assembly line. Adjustability has generally not found its way into the home environment, however.

Clearly, people with disabilities exhibit anthropometric variability; in some critical dimensions, like reaches, people with disabilities show greater variability than others. Yet designers often do not include this important and variable population in a design unless they are specifically designing a wheelchair-accessible restroom or other targeted space. For the most part, designers, architects and building planners have not deliberately avoided accommodating people with disabilities; they have been hampered by a lack of appropriate anthropometric data on which to craft a truly universal design. This paper will document current anthropometric resources on people with disabilities, and identify what needs still exist. I will close by outlining a research plan designed to address those needs.

CURRENT RESOURCES

There are a number of studies on basic anthropometry of people with disabilities and of the elderly. Most of these have relatively small sample sizes (under 100), which make it risky to generalize to a whole population for design purposes (1, 2). Some have larger samples, but are not from U.S. populations, and are therefore of limited utility (3). Still others (4) have adequate sample sizes, but have dimension lists that are focused on specific applications such as seating, so the usefulness of the resulting data base is restricted.

More than the lack of dimensions and small sample sizes, there is a problem in comparability of dimensions among studies. In an extensive review, Goswami (5) found that there was little uniformity or standardization among measurement techniques. This makes it impossible either to compare data from different studies, or to combine data from different studies to approximate a national general data base.

A number of the studies cited above compared a disabled sample to a non-disabled sample, either measured by the same techniques or taken from the published literature. In every case, the conclusion was drawn that there are important differences between the disabled and non-disabled populations. These differences are sufficiently large that the plentiful anthropometric data available for the non-disabled population should not be used for design tasks where the intended user population has a variety of disabilities.

It is now becoming understood that the very measurement techniques used for the non-disabled population are inappropriate for the disabled population. This is because standard procedures often require specific subject positions that this population may not be able to hold. Reaches, for example, a critical class of design dimensions, are very different when the starting position is sitting in a wheelchair instead of standing. There has been some work on developing appropriate techniques (6, 7), but these tend to be fairly application specific. Further, as Goswami (5) pointed out, there is little correspondence between techniques developed in different laboratories.

There is a fair body of literature on range of motion and kinematics (8). Because of the intense and time-consuming nature of data collection in this field, sample sizes over 20 individuals are rare. This makes generalization to the population difficult. I might also add that some of this information is misplaced with respect to design. Specifically, much of the effort is directed towards the path a limb takes from point A to point B. That pathway information is very useful clinically and therapeutically, but is considerably less important from a design point of view. We need to know how far away we can place the object at point B; we generally do not need to know how the user gets his or her limb to that point.

Finally, there have been some anthropometric studies aimed specifically at product and design. A number have focused on ramp design and placement (9), and others on the design of wheelchairs (10). The work in seated workspace design has centered on computer workstations (11). The limitation of all these studies is that the number of dimensions is restricted, quite reasonably, to the focus of the specific design. The result of this focus, however, is that there is no general large data base of Americans with disabilities.

NEEDS ASSESSMENT

A major nationwide anthropometric survey of individuals with disabilities should be conducted. Such a study would be designed to collect information including body sizes, reach capabilities, range of joint motion, strength, and visual field data from several thousand children and adults, aged two and older with a wide variety of disabilities. The resulting database would be widely useful to engineers, architects, designers, and manufacturers of products that allow people with disabilities and the elderly to live independently. Such an undertaking would, of course, require a large number of dollars. But compared to the current loss of human potential due to the inaccessibility of jobs, workspaces and living spaces, and the inadequate or unsafe fit of protective products, the dollar cost is relatively low. Certainly the cost-benefit analysis for such a survey would be extremely positive. We recommend the large survey here as a long-term goal. There are a number of ways to achieve the goal. One of these is cooperative government and industry funding. This mechanism is becoming more frequently used in other arenas, and should work here as well.

For the time being, we are recommending a pilot study whose purposes would include: 1) to provide specific anthropometric data on a general U.S. population of people with disabilities; and 2) to provide the groundwork to support expanded anthropometric surveys in the future by establishing sampling strategies, and by standardizing measuring techniques and data handling procedures.

A PROSPECTUS

An anthropometric survey of this population presents a variety of challenges not encountered in similar studies of non-disabled subjects, but on the whole, planning and organization are the same for both. The major tasks to be completed in the planning stage of any survey are the following:

- Select the target population.
- Establish a sampling strategy.
- Select and define the dimensions to be measured.
- Establish and test measuring techniques.
- Determine allowable errors for measuring each variable.

Target Population

One of the drawbacks of previous studies is that they have been very specific in nature. While each was scientifically sound for its purpose, the limited scope makes it difficult to generalize to the larger population. That said, perhaps the most difficult problem presented by this population is its diversity. Disabilities may be caused by a wide variety of diseases and injuries, as well as environmental and congenital conditions. Although a full-scale survey should be very general, and not limit the nature of disability, it may make sense to limit the population in a pilot study. However, one of the critical purposes of any anthropometry pilot study is to discover the amount of the variation that will need to be sampled in the full-scale survey. So, if the pilot study population is to be limited, then it should be limited in a way that will preserve the anthropometric variability present in the larger population. It may be that the earlier studies may provide some guidance in how best to accomplish this.

Recruitment of appropriate subjects must be carefully planned for, even when such subjects are widely available. In this case, appropriate subjects are not widely available. Arrangements will have to be made to seek out appropriate subjects in places where they are likely to be found in some numbers. One goal of major nationwide surveys is to maximize the diversity of the target population in the sample, not only with regard to sex, age, and racial/ethnic diversity but also with regard to geographic spread. For a pilot study – and perhaps even for larger future studies – geographic diversification is not likely to add anything useful to the variability of the sample. It should be possible to recruit enough subjects in or near any large city.

Sampling Strategies

Sampling involves the process of selecting a group of individuals thought to be representative of an entire population. To put it another way, the small number of individuals in a given sample must reflect a significant amount of the variability extant in the entire population. Accurate sampling is critical to the creation of a database that can be applied successfully to the purposes for which it is intended. As has been noted, the variability of the target population in this country is very great.

There are a number of sources of information on the size of various U.S. populations with disabilities, including the National Health Interview Survey (NHIS). Publications of various associations representing specific disabilities also produce statistics, but these reports do not give the kind of categories that would be useful in developing a sampling plan.

Ordinarily in sampling for anthropometric surveys, a multi-dimensional matrix is drawn up to make sure that all critical sources of anthropometric variability are accounted for in the eventual sample. In the Army's most recent anthropometric survey, for example (12), the matrix included sex, race and age. This is because these three demographic parameters account for much of the anthropometric variability in a non-disabled population. While the matrix approach is useful for the population of interest here, the same three parameters are not particularly effective. This is because the type of disability has much more to do with eventual body size and shape differences than does race. Age and sex are still important in defining a population of people with disabilities, so those parameters remain.

Dividing a wheelchair population into significant groups for sampling purposes is problematic. One approach is that suggested by Kumar (13) in Table 1. When developing this into a sampling strategy for a pilot study, one would select the most frequent 4 or 5 conditions, and group the rest into a category "Other". For a full-scale survey, with a more complex sampling strategy, one would be able to use more specific categories, and reduce the number in the "Other" group. Following this scenario, a sampling matrix might look like the one shown in Table 2. This is based on a total sample of approximately 250 subjects of a single sex. The figure would be repeated for the other sex, for a total of 500 subjects.

TABLE 1
Frequency of Medical and Physical Conditions Necessitating Wheelchair Use

CONDITION	PERCENT
Arthritis	28
Organic nervous disorder	14
Cerebral vascular disease	13
Bone injuries and/or deformities	11
Lower limb amputation	9
Cerebral palsy	8
Traumatic paraplegia	7
Respiratory and cardiovascular disease	5
Obesity, congenital errors, spinal injury	5

TABLE 2
Hypothetical Sampling Matrix

AGE	ARTHRITIS	ORGANIC NERVOUS	CEREBRAL VASCULAR	BONE INJURIES	OTHER	TOTAL
18-25	17	9	8	7	21	62
26-38	18	9	8	7	21	63
39-50	17	9	8	7	21	62
50-65	18	8	9	8	22	65
TOTAL	70	35	33	29	85	252

Kumar's distribution is based on data that were gathered in the U.K. Similar information for the U.S., if available, should be used in an actual sampling plan.

There are a number of ways to establish a reliable sample size. These include the familiar power curve, as well as formulas that estimate a specific *n*. In either case, the results will be largely the same. The assumption in either approach is that we understand the level of anthropometric variability in the population. That is why we should not artificially reduce variability in a pilot survey. We need to have the results of the pilot survey to estimate accurately the variability in the population as a whole.

Selection of Dimensions

Based on our survey of the literature, and contacts with people working in the area, the single most needed anthropometric datum, by far, is arm reach. Sitting height is also important for drawing up standards, as are some dozen other assorted variables such as grip strength and foot length. Planning and executing even a relatively small anthropometric survey is a costly undertaking, and if it is to be done, the addition of a reasonable number of variables for which there will clearly be other uses, such as wheelchair design, will not significantly add to the cost. For this survey we suggest variables that fall into five categories:

- basic body size descriptors
- reach and functional reach measurements
- arm and hand strength measurements
- field of vision measurements
- wheelchair-plus-user measurements

A recommended dimension list is available but space does not permit its inclusion here.

Measurement Techniques

This can be one of the most important outcomes of the pilot study. We can envision a cooperative nationwide full-scale study conducted simultaneously by a number of investigators. While this is not as desirable as having the same investigators collect all the data, it might be an acceptable and more cost-effective alternative. Such an approach is only feasible if each investigative team uses exactly the same measurement techniques. This is why the sound development and clear documentation of measurement techniques is so critical, and why this can be one of the most critical results of the pilot study.

We recommend developing the techniques in conjunction with users of the anthropometric data. This will assure that dimensions are defined in the most effective way. At the same time, it is important to define the dimensions to minimize the opportunity for observer error. Although it has not been feasible until recently, we now recommend documenting measurement techniques using a digital video camera. Images and clips can then be easily shared with other investigators over the internet. We also recommend establishing allowable observer error for each dimension. This will allow new investigators to judge whether their practice has been sufficient and whether they are ready to begin actual data collection.

CONCLUSION

The development of a nationwide anthropometric data base for people with disabilities is a crucial component for the successful accommodation of this population. As such a survey would be a significant undertaking, we have recommended beginning with a pilot study, and have outlined some of the factors which need to be considered in planning a successful anthropometric survey.

In the longer term, we see the results of this data collection being used to drive the development of digital human models. Such models will be the design platform in coming decades.

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USER PERFORMANCE WITH CONTINUOUS SPEECH RECOGNITION SYSTEMS

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ABSTRACT

The University of Michigan Rehabilitation Engineering and Research Center (UM RERC) on Ergonomics is just beginning a three-year study on user performance with continuous speech recognition systems. The application of speech recognition to the computer access needs of people with disabilities continues to grow, and a greater understanding of user performance with such systems is needed. This paper outlines what is known about user performance with speech recognition systems and presents the plan of a project designed to enhance understanding in this area.

STATEMENT OF THE PROBLEM

Continuous speech recognition (CSR) systems have the potential to greatly improve the productivity and comfort of performing computer-based tasks for a wide variety of users. These systems allow data input into a computer simply by speaking into a microphone, without requiring the speaker to pause between each word. For users whose severe physical disabilities require them to have some sort of hands-free access to a computer, CSR is an attractive option compared to potentially less efficient methods such as mouthstick typing or two-switch Morse code. For users whose use of "standard" manual input methods has led to a repetitive stress injury or other serious biomechanical stress, CSR may provide a productive alternative to continued discomfort and exacerbation of the injury, freeing users from keyboard use and its associated postural constraints.

While the promise of CSR is enormous and sales of voice recognition systems continue to grow, some basic questions regarding user performance with voice recognition have not been satisfactorily addressed. These include:

1. What is the range of productivity that a user of a CSR system can expect? How does this depend on the characteristics of both the user and the task?
2. What is the learning curve associated with CSR systems? How long does it take to develop a high degree of proficiency?
3. Are there human factors costs that may partially counteract the benefits of using CSR systems?
4. If so, are there methods of assessing for and delivering CSR systems that can reduce the impact of these costs and result in improved user satisfaction and productivity?

This study will provide a fuller understanding of the role of CSR systems in meeting the needs of people with disabilities by addressing these questions. The project will apply this new understanding to devise and evaluate methods of improving user performance with CSR systems.

BACKGROUND

Voice Recognition (VR) Systems

Automatic voice recognition (VR) has been under development since the early 1970's. Early systems could recognize only a handful of discrete words or utterances. By the late 1980's, recognition vocabularies of several thousand words became available, with the requirement that the user speak each word consistently and discretely, with short pauses between words. Discrete word VR systems have continued to improve in vocabulary size and recognition accuracy. In 1997 a major breakthrough in VR technology occurred with the first consumer-affordable continuous speech recognition system. Continuous speech allows users to speak at their natural pace and rhythm, resulting in faster and potentially more satisfactory interaction.

User-System Performance for Discrete VR Systems

The vast majority of existing literature on user performance with VR deals with discrete systems only. One metric of user-system performance is the recognition rate, measured as percent of words accurately recognized. One early system, with a limited vocabulary of 70 utterances, was able to recognize up to 90% accurately for a well-trained able-bodied subject (Dabbagh and Damper, 1985). More advanced systems, with several thousand word vocabularies, have reported recognition rates of 94% to 98% for well-trained subjects with and without severe upper extremity disabilities (Karl et al., 1993; Dalton et al., 1997). This is comparable to the accuracy of a skilled typist or mouthstick user (Dalton et al., 1997).

A second performance metric is overall user productivity. Discrete VR systems may or may not provide improved performance relative to standard input methods, depending on the task and subject population. For example, Karl et al. (1993) observed that when able-bodied subjects used voice instead of a mouse to enter word processing commands, time for four specific tasks was reduced by 19%. In a similar experiment for spreadsheet tasks, however, subjects performed more slowly with the voice interface (Molnar, 1996). Zemmel (1996a, 1996b) concluded that discrete VR was inadequate for medical emergency room and radiology dictation based on observed performance in those environments.

For general dictation and text entry, which is an important VR application for users with disabilities, performance with discrete VR systems has steadily improved over the years. For one early system, in which the user spelled out each word using the military alphabet, text entry rates of approximately 8 words per minute (wpm) were achieved (Dabbagh and Damper, 1985). By 1997, rates for highly skilled able-bodied users approached 25-30 wpm (Mello, 1997), not generally competitive with skilled touch typists but perhaps sufficiently fast for certain workplace dictation tasks. There are very few reports directly comparing text entry rate with VR to other input methods for users with physical disabilities. In one single case study, a well-trained user with a high level spinal cord injury achieved 20 wpm with a discrete VR system, as compared to 13 wpm using his mouthstick on a standard keyboard (Dalton et al., 1997).

Human Factors Issues in Discrete VR Systems

Human factors issues with discrete VR systems are important influences on user performance. While several such issues have been mentioned in the literature, including learning/training, other cognitive and perceptual aspects of interacting with a VR system, the capacity of the human vocal system, and the task environment, there are very few specific reports examining their quantitative impact on user-system performance.

Learning and training is one of the most frequently mentioned issues (Horner et al., 1993; Biermann et al., 1992). For successful use of a discrete VR system, the system must learn how the user speaks, which typically involves a standard enrollment process where the user says specific words in response to system prompts. The user must learn how to speak in such a way as to maximize recognition accuracy, by using a consistent tone of voice and the proper pause between each word. The user must also learn the most effective technique for correcting the system when the inevitable misrecognition occurs.

The time and effort involved in learning effective use of a discrete VR system, as well as in repeatedly deciding on the optimal correction strategy for each misrecognition, are examples of the "cognitive cost" of using the system. Other examples are the conscious effort required to speak each word discretely and then to monitor and manage the system's recognition response. This response typically takes the form of a "pick list" of candidate words that potentially match the user's utterance; the user has the option of visually searching this list for the correct word and choosing it verbally. The presence of these cognitive activities is what primarily distinguishes use of discrete VR from speaking naturally in a conversation. The need to engage in them frequently during human-computer interaction can be both tiring and time-consuming to the user (Card, Moran and Newell, 1983; Koester and Levine, 1996). For example, in a clinical case study the time involved in correcting misrecognized words accounted for more than 50% of the task time (Koester and Hilker, 1995, unpublished).

There has also been some suggestion in the literature that use of voice recognition can have unanticipated physical consequences. While decreasing the biomechanical load on upper extremities and postural systems, discrete VR can exact a greater load on the vocal system. This may cause only minor discomfort for some, but Kambeyanda et al. (1997) report on four individuals who developed chronic vocal stress requiring treatment after one year of using a discrete VR system.

Finally, the conditions of the work environment in which VR is used can have a significant impact on user performance. Key characteristics include placement and stability of the microphone, workplace background noise, and the extent to which VR use disturbs others in the environment. Zemmel et al. (1996a, 1996b) found VR not suitable for hospital emergency room or radiology environments due to background noise and other environmental issues.

Subjective comments of discrete VR users corroborate the presence of some significant human factors issues. Even users who enjoy using VR overall have commented on short term memory challenges and consequent interference with task domain, "tedious" nature of talking all the time, voice fatigue, and the frustration of attending to and correcting errors (Biermann et al., 1992).

User-System Performance for Continuous VR Systems

Continuous speech recognition (CSR) systems which will recognize tens of thousands of words are now available for less than a few hundred dollars. Popular reviews of such systems suggest that users can employ natural speech at their natural pace, with resulting dictation speed of up to 100 wpm and 95% recognition accuracy (Mello, 1997; O'Malley, 1997). However, we have found no empirical validation of these claims in the literature, either for "mainstream" or physically disabled users.

While the ability to use natural speech at a natural pace would be expected to reduce the impact of human factors issues on performance with CSR, many of the cognitive and perceptual activities required for interaction with a discrete VR system are still present with continuous speech recognition. In particular, misrecognition errors still occur, and need to be identified and corrected. This process is in fact somewhat more complicated than with discrete VR, since there are more choices for when to check for errors and how to correct for them. Effective interaction still requires development of a mental model of how the system works, an understanding of which error correction strategy is best suited to a particular situation, shared attention between the task domain and output of the CSR system, and memorization of specific commands for executing the chosen error correction strategy. To date there have been no reports of how these activities impact user performance and satisfaction, or how to design effective training interventions to reduce any negative impact they may have.

Implications

The above review reveals the following major gaps in understanding user performance with voice recognition systems:

1. There is only a small amount of user performance data with discrete VR systems, and almost none on continuous speech recognition systems. Very little of the existing data focuses on users who are physically disabled.
2. Human factors issues involved in the use of VR are briefly discussed in most studies, suggesting that cognitive/perceptual overhead and the potential for vocal stress may in some cases combine to significantly reduce user performance and comfort, but the magnitude and prevalence of these effects have not been reported.
3. An ergonomics perspective has not been a primary focus. Interventions which may enhance user performance, such as redesigning the work task, sharing input between voice and other channels, or customizing user training, have not been explicitly discussed or studied.

EXPERIMENTAL DESIGN AND METHODS

Overview

The UM RERC project plans to address these gaps through a series of experiments, divided into a baseline phase, an intervention phase, and an evaluation phase. The baseline phase consists of three experiments, each examining user performance with CSR systems from a different perspective. In the intervention phase, new intervention methods will be developed based on findings of the baseline phase. The evaluation phase will evaluate the success of these new methods at enhancing user performance by repeating some of the protocols employed in the baseline phase.

Baseline Phase

Clinical Case Review. Clinical files of clients who are using CSR systems will be examined in order to get a clear understanding of current practices and level of success. For each client, the case review will assess client and clinician expectations of performance with the CSR system at time of recommendation, and answer such questions as: Why was a CSR system recommended? What other possibilities were rejected and why? Were specific productivity goals established for this client? What training methods were used? Clients will then be contacted directly by telephone to assess their current usage patterns and satisfaction with the system.

Longitudinal Study of Novice Users. This will track the user performance of twelve CSR novices from first introduction of the system through the development of at least "intermediate" proficiency. User performance on paragraph dictation tasks will be measured at four intervals from system introduction to final recommendation, then once each at system delivery, six months post-delivery, and twelve months post-delivery. Sessions will be videotaped, allowing for measures such as recognition rate and overall words per minute, as well as detailed analyses of time costs associated with recognition errors and other component activities. Users will also complete a survey of user satisfaction and other subjective measures at the end of each test session. Both the quantitative performance and survey data will be analyzed. Subjective information from clients and their clinicians will also be used to better understanding the factors that influence user performance (e.g., human factors issues, service delivery issues).

Study of Expert Performance. The performance and satisfaction of at least six individuals who are frequent, highly practiced users of CSR systems will be measured using methods similar to the longitudinal study described above. Data will be compared to that from the novices at twelve months post-delivery to determine whether novice performance after one year approaches that of experts. Subjective information gathered from the expert users will build understanding of how expertise is achieved.

Intervention and Evaluation Phases

The purpose of the intervention phase is to design new or revised intervention methods in order to enhance user performance with CSR systems. These will be based on the findings of the baseline phase. For example, baseline data from novices and experts will provide a much clearer picture of the range of performance that can be expected. This can then be compared to the demands of a task environment as well as the expected performance with other input methods to predict and test the potential of CSR either alone or combined with other methods in meeting a client's needs. As a second example, detailed analysis of videotaped sessions will yield a better understanding of any performance "bottlenecks," e.g., due to difficulty in choosing the best error correction method, difficulty in remembering system commands, or other cognitive challenges in using the system. Methods to reduce the effect of these can then be implemented and tested, possibly through revised training methods or simple memory aids. If viable interventions are identified, longitudinal studies with a new novice group will be repeated for more comprehensive assessment of their effectiveness. Interventions will also be employed with the original novice group and a comparison made with the new novice group exclusively trained with the interventions.

We expect this three-year study to provide insight into the human factors issues involved in the use of continuous speech recognition systems as well as information regarding service delivery methods to enhance user performance with CSR systems.

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ERGONOMICS OF A NON-VISUAL TOUCHSCREEN INTERFACE: A CASE STUDY

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ABSTRACT

This paper outlines the process through which a hybrid interface was developed for touchscreen products for individuals with low vision and blindness. A case study approach is used in order to best convey the different lessons learned in the process as well as to provide the best understanding of some of the factors involved in designing interfaces for public systems that are usable by individuals with partial vision and with no vision. The final solution is a highly flexible hybrid technique which can be applied across, not only touchscreens, but many other types of interface.

THE PROBLEM

The problem that was addressed in this effort was the development of an effective alternate interface that could be built into standard touchscreen products. The primary target product was information and transaction kiosks. This would encompass a wide range of systems that might be designed around a touchscreen, including information kiosks, fare machines, building directories, ticket vending machines and advanced ATMs. The technique would also be applicable to much smaller devices with touchscreens such as palm pilots, although this is not the original target application.

The overall project was focused on developing cross-disability accessible interfaces that would maximize the number of people with different disabilities who could use public information and transaction machines. This discussion will focus just on the aspects that dealt with low vision and blindness, although it also includes access for individuals who might have trouble reading screens for reasons other than low vision (dyslexia, low or no reading ability, etc.).

The reason for the focus on these particular devices was that there was the rapid proliferation of touchscreen devices, and the similar lack of any effective mechanism for providing access for individuals with low vision or blindness to these devices. Since the devices are designed for use in public environments, it created a number of particular constraints on the solution strategy.

1. The techniques had to be something that could be easily built into the products but which did not change the way people who did not have disabilities would interact and use the product.
2. The technique had to be something that someone could come up to and learn without the benefit of prior training or anyone to assist them in figuring out the technique.
3. The various techniques for individuals with different disabilities (low vision, blindness, hearing impairment, deafness, physical disability, cognitive and language disabilities, etc.) had to be implemented in such a way that an individual with one type of disability couldn't

accidentally put the device into a mode which was designed for another disability and which they would be unable to extricate themselves from.

4. The technique should take into account the fact that an individual might have multiple disabilities.
5. The techniques had to work with a very wide range of screens and interface elements on the screen, including:
   - touch buttons
   - text fields
   - scrolling text fields
   - checkboxes
   - radio buttons
   - onscreen keyboards
   - scrolling hotlists (where each item in a list on screen acted like a button)
   - screens that updated themselves
   - and more

SOLUTION I

In the first design the approach for individuals with low vision was to provide additional information required in order to use the machine in the same fashion as everyone else. Individuals with low vision could typically see where the text and buttons were on the screen, but were unable to read the text (on the screen or buttons). Also, in some cases, their vision was poor enough that they could not get an overall impression of the layout of the screen. To address access for people with low vision, therefore, two features were provided.

1. A description of the overall layout of the screen.
2. A means was provided where the individuals could touch any text on the screen and have it read to them (including touching buttons without having them activated).

To do this, we added a single, large green diamond shaped button immediately below the touchscreen. Pressing and releasing the button would cause the description of the screen to be provided. Holding the button down and touching any text or buttons on the screen would cause them to be read aloud. In this fashion, the individual could explore the screen by touching items with their fingertip and having the various items on the screen read to them. Individuals with moderate vision would only need to use this "Quick Help" feature only for that text which they were otherwise unable to read. This technique also allowed individuals who used a device regularly to be able to use whichever parts of the device they could operate from memory in the same quick and efficient touchscreen fashion as anyone else and only use the quick help feature to explore those buttons they were not sure of. If they encountered new screens, they could also use the Quick Help feature to explore the new screens.

For individuals who are blind, an auditory mechanism was provided to allow them to explore the screen. They would invoke this technique by running their finger across the top of the touchscreen. Thereafter, they could use their finger to touch anywhere on the screen and it would read the text to them without activating the items. If they touched the extreme upper left-hand corner, an overall description of the screen would be provided to them. They could then slide their finger around on the screen to explore it. The following auditory cues were provided to help them explore the screen auditorially.

1. Touching the upper left-hand corner provided a description of the overall layout of the screen.
2. Whenever they slid their finger across a blank area of the screen, they would hear a white noise, not unlike the sound of running your finger across a piece of paper.
3. All of the edges of the buttons had an acoustic "edge" to them. This edge gave a different sound when one encountered it moving into the button then when one was leaving the button.
4. A different sound was provided when entering or leaving a text field.
5. Whenever a button or text field was entered, the name would be announced.

In this fashion, the individual who is blind could slide their finger around on the screen based upon the description of the screen and locate the various buttons and text fields. When the person wanted to activate a button, they would first find the button on screen, then lift their finger off the screen and press the large green diamond shaped button immediately below the screen.

RESULTS

This technique worked extremely well for individuals with low vision. It allowed them to use their residual vision wherever it was good enough, yet provided a quick and easy method for them to read any text that was beyond their vision. The technique also worked very well for individuals who had difficulty in reading the text on screen for any other reason.

Individuals who are blind (and those with very low vision) found the "slide-the-finger-around-the-screen" technique to be extremely interesting. The initial people to try the technique (who turned out were all technically adept), found the technique awkward for the first couple minutes since they were not accustomed to sliding their finger around to explore things. (Note: The normal motions that people who are blind use when searching are usually up and down patting motions. For example, when looking for something on a desk, they would pat around on the desk rather than putting their hand on the surface and sliding it around - which would quickly end up tipping things over.) Once they got past the awkwardness of sliding their finger around, however, they expressed delight in being able, for the first time, to get an idea of what these screens looked like to people who could see. All were quite taken with the technique and enthusiastic about it since it gave them their first opportunity to actually use touchscreen devices. They all also dismissed any initial disorientation that they had felt saying that they were able to quickly acclimate to the technique and once they were use to it, were able to successfully navigate all the screens.

LESSONS LEARNED

What we were experiencing at this point in the process is what most innovators experience when they first show a device to someone that allows that person to do something they could not do before. The device is instantly declared a success and the developer is left believing that they have discovered the answer, rather than thinking that they have discovered an answer that may or may not be anywhere near optimum. The people trying the device have seen nothing that was nearly this good and can, therefore, express tremendous optimism leading the developer to prematurely believe that they are near the best answer.

A second common misstep is to try solutions only with those individuals with whom one is familiar (who are usually quite technically adept) or only with those who volunteered to try the device (who are, by nature, either adventuresome, exploratory, technically adept, or all three).

MORE RESULTS

Encouraged by these early results, we began trying the technique with large numbers of individuals at disability conferences. Individuals showed varied learning curves, but with 1-5 minutes of practice and instruction were able to master the technique and explore and use a wide variety of screens, including a campus map with buildings numbered.

At one conference, however, we encountered a user who helped move us to the next level. She entered the area where we had our system set up but initially stayed at the far end of the room against the wall and just listened. After 15 minutes of gentle and friendly coaxing, Trace staff were able to convince her to come over and try the technique. When she tried the technique, however, she was completely and totally unable to use the technique. In addition to being blind, she appeared to have spatial perception problems so that even if she had just left a button, if she were asked to return to it, she would head off in a random direction. Based on this experience, we made a point of seeking out more technically shy individuals and although none had the same difficulty as this young lady, many found themselves becoming confused in trying to understand the layout of the screen and/or locate particular buttons using just the audio cues as they slid their finger around the screen.

SOLUTION II

Based upon these latter results, it became clear that this approach worked well for individuals with low vision but that at least some individuals who were blind would have great difficulty in using this approach. Since the problem seemed largely one of spatial orientation, we decided to add a technique where all of the text and buttons on the screen were lined up in a linear list fashion. Further, the list was positioned along the left edge of the screen so that the individual who is blind would have no difficulty in tracking up and down the list by simply running their finger up and down the groove formed by the touchscreen and the left cowl. After incorporating sufficient hysteresis to prevent any chatter as individuals transitioned from one item to the next on the list, we came up with a technique that we called the "Speedlist."

To use the technique, the individual would simply run their finger from the top left-hand corner to the bottom left-hand corner of the screen to turn the speedlist feature on. Thereafter, they could quickly scan all of the items on the screen by simply running their finger up and down the left edge.

The first item at the top of the list was always a description of the overall function of the screen and the types of information and controls, which would be found in the list. A layered system of help was provided so that the individual could get a quick overview of the screen followed by additional, more in-depth descriptions by successively selecting and activating the screen description button at the top of the list. To activate a button on screen, the person would just find it in the list, then lift their finger from the screen and press the green diamond button below the screen to activate the chosen item.

RESULTS

Although adding this technique did not increase access for individuals with low vision or reading difficulties, the technique was far superior for individuals who were blind. In fact, the same blind users who were so enthusiastic about the "slide-the-finger-around" technique previously, now stated that this technique was so much easier and faster that they would never use the other technique except when they were curious and wanted to see how the screen was laid out for sighted users.

The major problem faced by people newly introduced to the technique was again the fact that it was sometimes difficult to get them to press and slide their finger up and down the screen. They still had a tendency to want to lift and tap or touch their way down the screen, as this was their normal mode of exploring things with their fingertips. Tapping, however, could cause individuals to miss items in the list.

Individuals who had very long fingernails faced a different problem. If they used their fingernails to touch the screen, they had no difficulty. However, the usual strategy for individuals who want to preserve their long fingernails is to use the flats of their fingers. This not only prevented them from being able to reach the top of the list, but it also usually resulted in their using a very wide area on the pad of their finger. As a result, whenever they would lift their finger from the screen, they would either roll their finger up or their fingernail would touch and select an item higher on the list than the one they desired. Due to the audible feedback, they could instantly tell that the choice had changed. However, it became very difficult for them to try to lift their finger straight off the screen. Since the touchscreens were pressure sensitive, however, these individuals could use a pen cap or any other round gentle object instead of their finger. This was not optimal but it was the work around for their problem.

A different problem, however, arose at this point due to the number of different techniques now available on the kiosk. At this point, we had: 1) a "Quick Help" feature for individuals with moderate vision problems, 2) a "Talking, Touch, and Confirm" feature (the descendant of the "Slide-Your-Finger" technique) for individuals with more significant low vision or serious reading problems, 3) a "Speedlist" feature for individuals who are blind, 4) a "Scanning" technique for individuals who had physical disabilities and were unable to use the screen or the touch and confirm feature, 5) and a "ShowSounds" feature for individuals who were deaf or severely hard of hearing. As a result, we now had a problem where individuals approaching the device needed to be able to figure out what the different techniques were and which one would address their needs. If they knew in advance the shortcut gesture to activate their desired feature, there was no problem. If they didn't, however, it was more involved. It was doable, but an introduction or training session of at least 5 minutes would probably be required for many users.

At this point in the process, the package was picked up commercially and deployed in a range of venues including shopping malls, airports, libraries, in conjunction with community information and job kiosks.

TRAINING MODULE

We spent extensive time, at this point in the program, trying to develop a training module that could be included on every kiosk. If the individual was familiar enough to already know the shortcut gesture, they could immediately use it (e.g., running your finger down the left edge for speedlist). Otherwise, when they press the green diamond button it would drop them into a routine where they could learn about the different techniques and select the one that was most appropriate for them. The module would then take them through a series of training screens to train them on how to use the technique.

However, no matter how much time we spent on this particular module, we were unable to come up with a module which would be clear and easy to use without any human intervention or assistance.

SOLUTION III

After many failed attempts to come up with the universal introduction and training module, we turned our attention to trying to simplify and combine techniques. At the same time, we were looking at how to apply these techniques across devices other than touchscreens. One problem, of course, in using it on techniques other than touchscreens, was that there would be no way of implementing a speedlist (unless the device had some other type of analog linear selector). This led us to consider the use of arrow keys to move up and down the speedlist (similar to a technique we had used earlier with keyboard based information systems with built-in speech). This would mean that we would have to add two additional buttons (arrow keys) to the green diamond button for the touchscreen kiosks. (Something we were trying to avoid.) Doing so, however, both enabled the technique to move between touchscreen and non-touchscreen based products, but also made it even easier for many individuals who are blind to use the speedlist function. Even in those situations where the speedlist was faster (e.g., typing one's name in using an on-screen keyboard) individuals who were blind expressed a preference overall for the arrow key approach, because it provided a much more discreet and definite stepping between choices. Although we had used a similar arrow key stepping technique in earlier work at the Center, we had not thought of using it in this context sooner, because of an assumption that was made early in the process. We had assumed that we would have a hard enough time getting one button added to the kiosk, and that we were unlikely to get multiple buttons added. Not revisiting that decision (and not realizing how much the decision was shaping the flexibility of our thinking) cost us considerable time as we wrestled to try to solve an over constrained problem.

LESSON LEARNED

Always be sure that you have at least one member of your team who is always revisiting and questioning any assumptions made in the process and any constraints imposed from within (and even those imposed by those outside the project team). This role usually falls to the newer members of a team who are both looking at the problem with fresh eyes and looking for a way to put their mark on a project. Both of these tendencies should be taken advantage of. It was fresh eyes on this project that got us past the 1 button assumption.

SOLUTION IV

Once we had broken the one button barrier and had moved to a three button approach, we quickly began to find ways to simplify the number of techniques. For example, a step scanning technique we had, which used the green diamond button and the screen, was replaced by using the three buttons and the list. After a short interval, this led to the final hybrid technique that allowed us to collapse all of the voice based techniques into just one technique with a second optional strategy. Moreover, this one technique could be used across all the disabilities (except hearing impairment which had a separate strategy, namely ShowSounds/Captions). By having a single hybrid technique that could be used across disabilities, it eliminated the need for a complicated training module and reduced the instructions to six sentences (which could easily be played when the individual first approached the product and pressed one of the EZ Access keys). Briefly, the hybrid technique works as follows.

- When an individual presses the green diamond shaped button, the instructions explain that the two arrow keys can be used to explore all of the items and choices on the screen and the green diamond button can be used to activate any item that the user finds while pressing the arrow keys (see figure 1).
- Pressing an arrow key causes a yellow outline to jump to the next item on the screen, highlighting it. At the same time, the name of the item is read aloud.
- Individuals with low vision (or those who have trouble reading the text on the screen for other reasons) are, thus, able to move the highlight around, exploring the items on screen.
- To individuals who are blind, it appears that they are moving up and down through an audible list of the items on the screen.
- Individuals with physical disabilities, who have difficulty either reaching or accurately touching the screen, can use the arrow keys to move to the desired items and then activate them using the green diamond button.
- In this manner, a single technique can provide access to the screen for individuals with low vision, reading difficulties (including an inability to read), reach problems and motor control problems.
- A button on the screen and also on the list provides access to the ShowSound/Captions feature for individuals who are hard of hearing or deaf. (Wherever possible, an amplified telephone handset that is hearing aid compatible is also provided. A headphone jack is also always provided for private listening and for coupling to assistive listening devices, inductive loops, etc.)

In addition, the Quick Help feature is still provided so that users with moderate vision loss can continue to use the touchscreen in its standard fashion and simply hold the green diamond button down to explore particular items on the screen which they might find difficult to see or read.

Finally, the entire scheme is set up to be non-modal so that it is possible to easily move back and forth between using the touchscreen with these enhanced features and using the touchscreen in its standard mode.

RESULTS

We've only begun the testing process on this latest hybrid mode. However, reaction from both consumers and manufacturers who have been involved in the past versions has been very enthusiastic. Consumers find it much more straightforward and definite in its operation. Manufacturers find it much easier to understand and implement. For the first time, we have also been able to have blind individuals, who have no prior knowledge at all of the EZ Access technique or the device they are trying to operate, walk up to an EZ Access equipped device and without any instruction successfully operate it. In one recent example, an individual who is blind, who had no knowledge of our work, who had also never used an ATM before in her life, was able to walk up to an EZ Access equipped ATM prototype, and with no difficulty, discover how the feature worked, check her account balance and then withdraw $5.

CONCLUSION

The purpose of this project was to develop a cross-disability extension to touchscreen interfaces that would allow general access to public touchscreen based appliances. The project was successful and the techniques are now being applied in airports, libraries, community centers and voting booths. The process, however, was iterative and took longer than we would like mostly because we did not fully understand the complexity of the problem – especially in developing interfaces which were cross-disability accessible.

This paper is designed to both highlight some of these issues as well as to provide insights into this type of research and development which might be useful to new researchers (and a reminder to us all).

In the end, it turned out that the best solution was a hybrid which gave pretty good access to a wide range of individuals, rather than having a collection of many different techniques each tuned to a particular disability. Although, tuned interfaces might be workable on personal devices (and may be necessary for the person's workstation), the complexity introduced by this approach on public systems turned out (at least in this instance) to be too much for many commercial vendors and for consumers who needed to approach a device and discover how to access and use it. The strategy which resulted in the most straightforward, definite, discoverable and recoverable interface won out over options and user efficiency—at least for these public information systems. Ease of understanding by companies who need to implement it was also a key factor.

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THE ROLE OF NEEDS ASSESSMENT AND REMOTE USABILITY METHODOLOGY IN DESIGNING TELESUPPORT SYSTEMS FOR USERS WITH DISABILITIES

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ABSTRACT

The term "telesupport" is broad and encompasses many different applications with the shared mission of relying on electronic means to deliver services that improve well-being by improving medical outcomes, facilitating adaptation to changes in physical and mental capabilities, and providing access to social and community support. Ethnographic research techniques and assessment methods as well as a suite of remote usability metrics are described that can be used to develop human factors design principles suitable for implementation in telesupport systems and other assistive technologies used by a broad range of disadvantaged users.

INTRODUCTION

While the challenge to developers of assistive technologies is to maximize function while minimizing complexity, the most frequent complaints of assistive technology users is that the systems are too complex (1, 2). Studies of long-term users of assistive technology have found that users prefer and are likely to comply with engineering designs that can be learned easily without radical interventions by others (2). Similarly, studies by Scherer and Lane (3) found that consumers were more accepting of products when they were able to make key decisions regarding design and service delivery. Thus, the design of assistive technology strongly influences technology acceptance, adoption, and quality of life. Unusable telesupport systems not only lead to user frustration and avoidance, but ultimately can disempower users and undermine overall health and quality of life.

"Telesupport" systems are assistive technologies used to deliver services such as information, healthcare service delivery and management, vocational rehabilitation and training, specialized education, social support, and community networking. Telemedical systems constitute just one type of telesupport, and can be one feature of a larger telesupport system. Telesupport systems can be especially important to individuals with disabilities. However, like telemedical and other computer-based assistive technologies, these systems have focused more on content rather than the social, functional, and cultural needs of potential users (4). Because these systems are either newly implemented or emerging as design concepts, very few usability principles have been developed or applied to software and hardware interface design and functionality.

It is problematic that assistive technologies such as telesupport systems have mimicked the same development philosophies that plague other computer-based systems, in that these systems do not consider the needs and capabilities of disadvantaged users (5, 6). As cultural artifacts, telesupport systems reflect the needs and values of the dominant, majority culture (7). Technological marginalization is a value system and a process that results in inequities in access and ultimately, inequities in the beneficial impacts of system use. Users with disabilities, the elderly, and ethnic and class minorities have become technologically disadvantaged through the process of technological marginalization. Much of this marginalization reflects long-standing misperceptions and resistance to universal design. Universal design is perceived as simply encompassing the needs of a small group of users and, as a consequence, is not believed to result in systems that are usable to all potential users. However, universal design which incorporates users with disabilities produces products that are not only beneficial to disadvantaged users, but to all users (8, 9).

The values of product development are also reflected in the design of most usability methods, which were developed and validated using samples of users from the majority or dominant culture. This renders their usefulness in effectively capturing robust data for disabled users highly questionable. Developers argue that the inclusion of users with disabilities will slow down the product development cycle, and thus increase the cost of product development (5). Similarly, some developers worry that users with disabilities will not be able to participate in traditional, face-to-face, empirical usability testing because of limitations in mobility and other challenges that may be associated with specific disabilities (e.g., need for special equipment and support during usability sessions). These same challenges may result in usability testing sessions that are inefficient or yield unusable data. Just as there are very few efficient methods to conduct usability testing that focuses on users with disabilities, the methods employed to assess user needs in general are not robust enough to capture characteristics and design concepts that reflect the needs and capabilities of special populations.

Thus, there is a strong need for usability testing methods that result in efficient and cost-effective user assessment and enhancement of user participation during the product development cycle. Two approaches that are particularly useful when developing telesupport systems are ethnographic assessment and remote usability methodologies.

RESEARCH METHODS

Ethnographic Assessment

Determining the needs and capabilities of users with disabilities is critical to developing usable telesupport systems. Some user needs and characteristics can only be validly acquired through ethnographic methods (10, 11, 12). Unlike quantitative assessment, such as quantitative measurement of performance or subjective experience, ethnographic approaches emphasize subjective experience and place value upon the unique experience of each user. Because these methods were originally employed by anthropology, an important characteristic of ethnographic research is the immersion of the observer in the user's environment so that more realistic data can be captured. When ethnographic assessment is applied, there is no need to bring users into the development environment. These methods are best applied by having the researcher conduct assessments in the environments in which users will access and use the telesupport system. Thus, when focusing upon users with disabilities, home or office visits are the most appropriate environments, and researchers should focus upon going to users rather than implementing logistical procedures to bring the users to the development environment. Immersion can be fully extended to the level of participant-observation by researchers allotting sufficient time to shadow users throughout a typical day. These approaches have the advantage of providing an opportunity to observe all aspects of the user's goals, needs, and preferences, without relying upon indirect inferences drawn from quantitative measurement.

Besides real-world immersion, additional user-centered ethnographic methods that can be easily implemented during telesupport systems development include focus groups, telefocus groups, and interviews. Each of these methods must be carefully planned in order to capture data that can be easily translated into design concepts, requirements, and features. It is important to develop topics and questions by consulting with individuals with disabilities and relevant experts, as well as members of the product development team. Consultations for implementation of ethnographic methods will support the acquisition of data useful to product development.

Focus groups are, by definition, focused upon a specific topic. Due to the similarities and shared experiences of focus group participants, group dynamics inherent in the group process facilitate the communication of useful data by enhancing participants' perceptions, memories, and honesty in reporting (13). These techniques also empower users by demonstrating the developers' recognition of the users as knowledge experts regarding their own needs, capabilities, and preferences, and therefore, central to the development process. In addition, focus groups can yield data on person-system/human-computer interaction by presenting an early prototype or mockup of the product to the participants.

Focus groups can be conducted in workplaces or support center environments in which at least 6 – 12 users with disabilities can participate. If necessary, users with disabilities can be provided with needed assistance to assure full participation with the help of trained assistants or family members. If it proves difficult to assemble users in one physical location, a telefocus group is a useful way to take advantage of the focus group dynamic without imposing travel demands. A telefocus group can be conducted by using telephone, audio-only, or video conferencing tools installed with adaptive equipment customized to the needs of each participant. These tools can be installed in the homes of participants, repeatedly used for future development projects, and can be transported to new participants.

Even though users are not located in the same physical space, high-quality equipment and a well-trained focus group facilitator can build a shared dynamic that is useful in capturing valid data. Participants may require training to implement teleconferencing equipment, and some may need assistance during the sessions. However, these training and assistance needs are a minor investment when considering the usefulness of the data and the savings in time and cost. Since telefocus groups are relatively new, little research has been conducted on their usefulness; but if viewed as another form of cooperative work, some research on communication patterns in computer-supported cooperative work applies. For a comprehensive discussion of communication in computer-supported cooperative work, see Kies, Williges, and Rosson (14).

Structured and unstructured interviews can be used along with or in lieu of the focus group method. The interview technique is particularly useful when a participant's disability precludes focus group participation, or when data gathered from a focus group session needs confirmation or extension. Questions designed to gather user impressions, descriptions, and preferences can be gathered using structured or unstructured interviews. However, to ensure that usability-related data are captured, it is important to identify scenarios or tasks that can be administered through an interview method. Again, consultations with individuals with disabilities, experts who provide support services, and members of the project team are particularly helpful in designing questions that will yield usability-oriented data. Mockups and prototypes can also be used during interviews in order to test concepts or features.

Although ethnographic techniques are very important in capturing user-centered data, if used alone, they may not yield comprehensive data. Quantitative methods to capture objective and subjective data are also effective. The most valid approach is a mixed-methods approach, which combines ethnographic assessment during early system design with quantitative measurement of user performance when a functional system prototype has been developed. Ethnographic approaches can continue to be applied during prototype implementation.

Remote Usability Assessment

Remote usability assessment is defined as "usability evaluation wherein the evaluator, performing observation and analysis, is separated in space and/or time from the user" (15). This method supports usability testing in environments where access to the central development location or to users of the system is difficult, time-consuming, or costly. The method can also capture data continuously, thereby facilitating participatory and iterative design. A major advantage of remote usability assessment is its ecological validity (16). The use of remote usability metrics can be a useful triangulation component when utilizing ethnographic methods. Users report incidents while implementing the system in their natural environments (homes, offices, etc.). It is this aspect of remote usability assessment that makes it particularly compatible with ethnographic methodologies.

Remote usability metrics that apply the critical incident technique are currently being developed and validated at Virginia Tech (17, 18). The critical incident technique was proposed by Flanagan (19) for systematically collecting observations of critical human behavior in a field environment. In the context of usability evaluation, a critical incident is defined as an interaction with a system feature leading to extremely good or extremely poor performance (20).

One challenge of remote usability assessment is the design of an interface to support user reporting. Thompson and Williges (21) describe a prototype web-based tool that includes central access to evaluation instructions, benchmark task scenarios, online critical incident report forms, and an online training tool for learning how to properly identify and report critical incidents. This tool can be used either in the laboratory or remotely. The critical incident reports are then submitted asynchronously to the experimenter who is responsible for compiling them into a list of usability problems. Although the current web-based tool provided an initial proof of concept, a complete suite of online techniques, methodology, and design principles needs to be developed and validated.

The overall goal is to develop a generic set of measures that can be easily tailored to applications relevant to various systems. Methodological issues that need to be investigated include: streamlining online data input, providing online classification of usability problems, training users to use online usability assessment tools properly, embedding and evaluating a variety of usability evaluation procedures, developing appropriate methods for evaluating various classes of users interfaces (e.g., graphical, textual, voice), and supplying accommodations required for users with disabilities to provide remote evaluations. These issues need to be addressed in laboratory research and validated during the field evaluations of the various telesupport systems in order to develop a taxonomy of remote usability evaluation metrics.

The universal design philosophy applied in the development of remote usability assessment can be transferred to products in which developers might apply it. The demands placed upon users with disabilities are greatly reduced by using remote usability assessment. Users are not required to relocate physically or implement additional equipment to participate. Remote usability metrics can be administered via computer during use of the telesupport system, and the measurement tools, procedures, instructions, and help can be embedded within the measurement package. Although this technique is promising, further development is needed to tailor the procedure to users with disabilities.

CONCLUSIONS

The focus of the Human-Computer Interaction and the Assessment and Cognitive Ergonomics Laboratory at Virginia Tech is to develop assessment tools that are easy, effective, and useful in capturing the needs and capabilities of users in general, with a specific focus on disadvantaged or marginalized users. One must apply critical design features captured from the assessment tools to the design of interfaces for technologies of well-being such as telemedical systems, assistive devices, and other support systems. To achieve our objective, system design should be based on user needs assessments, participatory design, and remote usability evaluations. In fact, Lin, Williges, and Beaudet (22) proposed a three-phase approach to user-centered design of assistive technology that incorporates (a) needs assessment, (b) assistive technology design, and (c) design validation. Ethnographic procedures can be used for determining user needs, and remote usability assessment can be used for design validation in this three-phase approach to the design of useful and usable assistive technology. Based on this approach, general human factors and ergonomic design principles for telesupport systems can be developed and validated to improve assistive technology utilization by disabled individuals.

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USE OF CONCEPTUAL MODELS FOR APPLYING ERGONOMIC TECHNOLOGIES TO OVERCOME BARRIERS TO WORK

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ABSTRACT

Numerous models have been proposed to help understand the relationship between personal and work factors that affect participation in work. We have proposed an enhanced model to facilitate the job placement and return to work decisions by health care providers. Model enhancements include a hierarchy of job assessment tools and inclusion of work related factors of musculoskeletal disorders.

INTRODUCTION

This paper is concerned with models and procedures for accommodating and overcoming physical barriers to work that will enable the greatest possible participation in work and society. Manual work continues to be an important part of our society. In spite of a strong economy and the demand for manual laborers, many persons with certain physical and mental conditions still experience difficulty finding meaningful work (1,2). In addition to persons who are unable to find work because of their health, there are people who have jobs, but are unable work because of subsequent injuries or illnesses. In many of these cases the job contributed directly to the illness or injury. There were 1,833,380 lost workday injuries and illness in 1997; 52.5% of those cases involved musculoskeletal sprains, strains, carpal tunnel syndrome, tendonitis and soreness and pain (3).

Numerous models have been proposed for describing the relationship between worker capacities and job demands, for formulating policies on disability and for collecting and interpreting worker and job data (4,5,6,7,8,9). There are too many worker and job attributes for them to all be considered at once. Models typically reflect the concerns and needs of their developers. Some models consider many factors at a very general level for development of policies, while others considers fewer factors at detailed level for worker placement. Some models emphasize physical factors while others emphasize medical factors. As a result models developed for application in one setting may not work well in another.

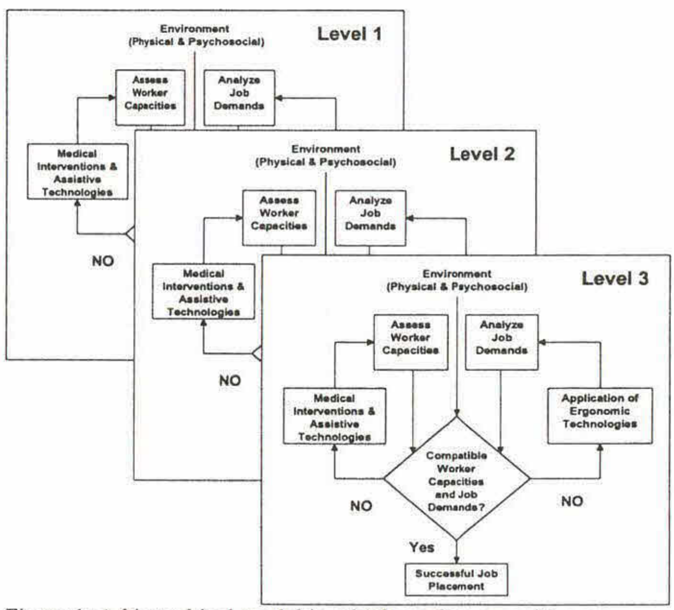

Figure 1: A hierarchical model in which worker capacities are compared with job demands to identify barriers to employment.

A MODEL

All of the models to some extent consider the relationship between the worker, the job and the environment. We have included these basic relationships in a model shown in Figure 1, but initial focus is on the physical aspects of this relationship. The model structure is hierarchical open-ended so that investigators can gather information incrementally to determine the nature of the problem and to focus data collection on problem areas. Although three levels are shown, more or less levels can be added as necessary to achieve the necessary level of detail for a given case. Some possible cases include:

1) Return to work of a patient who has experienced a work-related injury or illness.
2) Job placement of a person who has a non-work-related condition from birth, disease or injury.
3) Design of a new job to make the job accessible to the largest number of possible workers.

In the first two cases, the individual is generally under the management of a licensed health care provider (HCP) who has ultimate authority for the return to work or primary placement decision . It is the role of the ergonomist or the worker and employer themselves to collect information about the job and to provide it to HCPs so that they can make informed placement decisions. It is also their role to apply ergonomic technologies to overcome barriers to work. In the third case, the ergonomist utilizes published population norms and works directly with workers and employers to design jobs that anticipate and eliminate potential barriers to work.

The job analysis may be limited to those aspects of the job that pertain to a given condition or concern. For example, if the worker's condition involves hand or forearm pain, the analysis will probably mainly focus on what the worker does with his or her hands. If the complaint is of shoulder symptoms, the analysis will probably focus on the location, force and frequency of work. In the third case, it is necessary for the employer to anticipate and consider the characteristics of all workers who might apply for that job.

The job analysis is nominally divided into five Levels. The worker assessment can also be divided into multiple levels, but this discussion is concerned with the job assessment part of the model and providing information to HCPs so that ergonomic technologies can be applied to eliminate work barriers. The worker assessment will be described only at a Level 0. Further description of the job anlysis procedures is given (10).

A Level 0 job analysis is a descriptive job title; a Level 0 worker assessment includes the age and gender of the worker and the condition affecting their work capacity. A Level 0 assessment is intended as a meaningful way of referring to the job and case that provides insight into those aspects of the job and worker that will need to be evaluated to overcome barriers to employment. If a worker has carpal tunnel syndrome, the job analysis resources might be most effectively allocated to analysis of those aspects of the job that entail use of the hands. If a worker has rheumatoid arthritis that affects the entire body, then it may be necessary to analyze all of the physical task requirements.

Level I analysis is based on a structured interview of workers or supervisors. It is intended to gather information about 1) what the worker does (basic tasks, where they are performed, tools and work object used, and mobility, force and posture requirements) and 2) about work demands (reach locations, strength requirements, etc.) and factors associated with musculoskeletal disorders (repetition, force, etc.). In some cases, it provides enough information to determine if the job should be considered by or for a worker with a given capacity or what kinds of assistive devices, accommodations or safety measures might be required. In other cases it provides information about how to proceed with further study.

Questionnaires are sometimes used to gather worker information from workers about jobs, but they must be tailored to the type of work that is being studied or else they tend to be overly general. Interviews are more flexible than questionnaires, but care must be exercised so as to not bias the workers' responses (11).

Interview information often can be quantified by using worker ratings. Likert scales, Borg (1990) ratings of perceived exertions and visual analogue scales are widely used for this purpose (12, 13). In some cases, the analyst may design rating scales during the interview to obtain individual worker perceptions about a specific task or tool.

Level II analysis is based on direct work site observations and measurements and provides additional quantification of the data obtained from Level I. Formal work descriptions, standards, production data and observations should be obtained and compared with worker interviews.

An important part of the Level II analysis is describing a "standard" work method for each task, i.e., the steps by which the job can be performed to meet the specified production standard. Gibreth proposed a standardized set of elements or "Therbligs" for describing jobs and for identifying gaps between the work capacities and job demands for disabled veterans returning from the war.

Therbligs correspond to individual motions and acts, e.g., reach, grasp, move, etc. As a practical matter it often suffices to say get part rather than reach-grasp-move.

Some jobs do not follow a consistent sequence of work elements or tasks, e.g., clerical work or maintenance work. Work sampling is particularly useful in documenting these types of jobs. Many video cameras can be programmed to record one second of video every minute. These one-second clips are in most cases long enough to determine the work task, and if the hands are working or resting, and are preferred over still frames. The statistical confidence limit is related to sample size and the average proportion a given event is observed (14). Four-hundred-eighty one second video sequences typically require about two hours to analyze.

Level III job analysis is the application of standardized criteria for rating physical stresses associated with musculoskeletal disorders, e.g., repetition, force, contact stress and posture for each task and the overall job (see Figure 2). We prefer to have two or more persons rate the jobs independently and then discuss their ratings as a group to reach consensus. Ratings can be performed from videotapes or from direct observations of the job. Additional Level III analyses can be performed using NIOSH Work Practices Guide for Materials Handling (15), a RULA (16) or the newly proposed ACGIH analysis (17). The type of analysis performed would be based on the reason for the analysis, e.g., management of a back injury, shoulder injury or hand injury.

Video recordings of jobs are reviewed to extract a clip that reflects as closely as possible to the "standard methods." In some cases, multiple clips will be observed to document intra- and inter-worker variation and process variations. The video recordings are then used to rate ergonomic stresses: repetition, force, contact stress and posture (18). Two or more independent ratings are obtained and then discussed to achieve consensus.

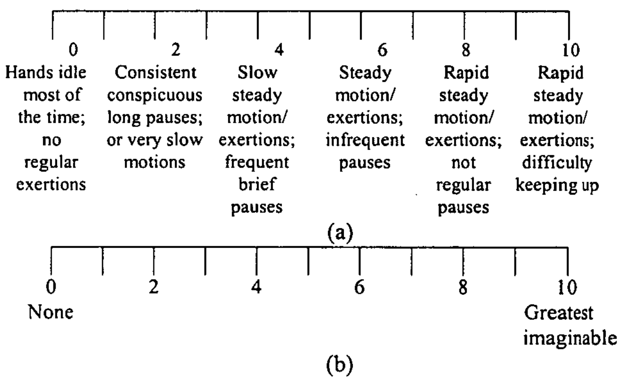

Figure 2: Scale for rating Hand Activity Level, HAL(a) and peak and average hand force (b) (17,18). Scale (b) is also used to assess contact stresses and posture stresses.

The ACGIH Physical Agents Committee (17) has recently recommended a TLV for hand activity based on the repetition scale recommended (18.19). In addition to using simple ratings, they also proposed a model based on hand exertion frequency and duty cycle.

Level IV uses instrumentation, e.g., goniometers, electromyography, force gages and accelerometers, to provide quantification of specific task attributes. Instrumentation is typically used to investigate a specific work barrier or to evaluate the effects of a particular intervention. For example, force gauges might be used to evaluate keyboard forces for a worker with a WMSD or to evaluate the benefits of one keyboard versus another. To illustrate application of the model two cases are presented.

Example 1 A 32 year-old right-handed female with bilateral forearm pain employed as medical billing clerk: This worker reported bilateral forearm pain that became worse after 1-2 hours of work. She was received extensive physical and laboratory examinations, which were all negative. Workers with symptoms but no abnormal findings on clinical examination or laboratory tests, represent a large fraction of the working population (18). Level 1-3 job analyses were performed on this workers job. Selected results are summarized in Table 1. It can be seen that the with the exception of peak forearm rotation, all of the ratings are on the lower third of the 10 point scale. Also, it can be seen that she rotates between many different tasks. Keying is only performed an average of 10% of the time. This information was made available to the health care providers who concluded that this job was an ideal light duty job for this worker. They also recommended that some type of follow-up seems advisable and that the worker should be encouraged seek further help if her symptoms worsened.

Table 1: Office/Clerical/Medical Billing Job Summary

Work station/equipment:
- Computer station w/ adjustable keyboard tray
- Documents on separate tables on right and left
- Phone with handset
- Conference room

Tasks/Methods:
- Keyboard 10%
- Mouse 4%
- View screen 8%
- Writing 1%
- View charts 25%
- View references 6%
- Phone 4%
- Away from desk 35%

Repetition: Low (3/10), some prolonged static exertions
Force: Medium peaks (6/10) to handle charts & docs
Contact: Low(<3/10)
Posture: Medium-high peak elbow for keying; medium average for neck to view charts & documents

Still there are a number of relatively low cost interventions which individually or taken together might be beneficial, such as proper adjustment of existing equipment; document holders, or a structured break schedule.

Example 2: 47-year-old male with left elbow pain employed on an assembly line for assembly of medium sized auto parts: This worker initially complained of left shooting pain from the elbow to the hand --- like hitting his funny bone. He also complained of difficulty sleeping. His initial physical and laboratory examinations were negative; however, later developed symptoms and signs of lateral epicondylitis and carpal tunnel syndrome. His HCP treated him with a nighttime splint and issued a work restriction of no lifting over 5 pounds and no repetitive flipping, twisting of hands or wrists. The worker was then placed on a job believed to be compatible with his restriction. Table 2 provides a summary of the major physical stresses associated with work related musculoskeletal disorders of the upper limb. There was little difference in repetition, contact stress, wrist flexion/extension and forearm rotation, but there were remarkable reductions in peak forces and contact stresses on the forearm and elbow, shoulder and back postures, but wrist radial/ulnar deviation was significantly increased. While the peak wrist radial/ulnar deviation postures were high (8.5/10), the average vales were low (2/10), which indicates the peaks are very intermittent.

Table 2: Major physical stresses (peak/average) associated with work related upper limb disorders before and after injury. (see Figure 2)

	Job Before Injury	Job After Injury
Ergonomic Factors:	Stock Loading	Put Seal on Piston
Repetition	5	4.5
Force	**6, 1**	**3, 1**
Contact Stress		
Finger/Hand	5, 2	4.5, 1
Wrist/Palm	5, 2	4.5, 1
Forearm	**3, 0.5**	**0, 0**
Elbow	0,0	0, 0
Posture		
Wrist Fl/Ext	7.5, 2	6, 2
Wrist Rad/Uln	**3, 1.5**	**8.5, 2**
Forearm rotation	7, 3.5	7, 3
Elbow	**7, 3**	**5, 3**
Shoulder	**9, 3**	**7, 2**
Neck	**9, 2.5**	**4, 1**
Back	**5.5, 1.5**	**3, 1**

The improvements in force, contact stress and forearm, elbow, shoulder and back postures appear to outweigh the increased peak wrist posture stress. Following placement on the light duty job, the condition of the patient's elbow, wrist, and hand improved. Had the patient's condition not improved, the ergonomic profile shown in Table 2, could be used by the employer and health care provider to identity barriers where ergonomic technologies could be applied to accommodate the individual under consideration.

The information system: These examples may seem trivial, but they would not be if the job data were not available. A case was described in which a worker was diagnosed with a musculoskeletal disorder and given a work restriction, but the restricted jobs were later found to be more stressful than the original job (20) And that was only discovered because the physician, who was based at the plant site, took time to go observe the job with the physician. Even in Example II above, it was found that even though the light duty job accommodated the worker's force restriction, it introduced additional wrist posture stress. In most cases the physicians are not able to take the time to visit all of the jobs. This is particularly true if they are not located at the work site. As a result they must rely on a Level I job assessment via an interview of the worker or telephone interview of the employer. This may not provide sufficient data to prescribe a meaningful work restriction. This is particularly a problem for a supervisor or other plant person who has to interpret the restriction. The problem is even more complex if the patient is being considered for a new job.

There is a need to make job information directly available to worker, health care provider, and the employer. Towards this end, we are developing a database of job analyses that can be used as examples to facilitate management of restricted workers. Information in the database can be made directly available to all parties via the internet so that it can be discussed via conference calls or net based meeting software. The database includes basic descriptive information: job title, standard, tools, material, work station, etc. It includes a methods analysis with ergonomic attributes for each work element or task. Also included are Level 3 ratings of the jobs. Finally the database includes video clips of representative work elements. Most people who use the database report that the video clips are the most important feature.

CONCLUSION

In conclusion the proposed model provides a flexible framework for collecting and considering worker evaluations and job analyses. An important feature of the model is that evaluation can be focused on the factors that are relevant to the case at hand. Populating the database with cases will make it possible to evaluate case management strategies and learn from previous analyses.

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WORKER ANALYSIS TOOLS FOR CONTROLLING MUSCULOSKELETAL DISABILITY

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ABSTRACT

Quantitative methods are needed for evaluating the extent of disability and level of recovery from a work-related musculoskeletal disorder. Our laboratory is developing functional assessment instruments for quantifying sensory and motor deficits in a work-related nerve entrapment disorder, carpal tunnel syndrome. The gap detection sensory test quantifies dynamic tactile inspection thresholds for areas of the hand innervated by the median nerve. The rapid pinch and release psychomotor test measures the initiation and control of specific muscles innervated by the median nerve motor branch. A total of 169 subjects were recruited from varying industrial settings, including poultry processing, automotive manufacturing, plastics manufacturing, general assembly, and newspaper publishing. All subjects completed a symptom survey, underwent a physical examination of the upper limbs, shoulder and neck, had a nerve conduction study (NCS), and were administered the Wisconsin Test Battery. The psychomotor and sensory test outcomes were related to objective NCS findings in combination with symptoms, but it is most interesting to note that no statistically significant functional differences were observed among subjects categorized by NCS, symptoms or physical exam alone.

INTRODUCTION

Two functional automated tests were developed for assessing disability in carpal tunnel syndrome (CTS). The sensory test (1, 2) quantifies the threshold for detecting a small gap in an otherwise smooth surface. The rapid pinch and release test (3) measures psychomotor function in a task that requires pinching two strain gauge instrumented bars rapidly at varying force levels. These tests are currently being studied in a population of industrial employees working in jobs considered high risk for CTS in order to longitudinally evaluate functional deficits associated with symptom survey reports of pain and discomfort, physical examination findings, and nerve conduction tests. The tests are also currently being used for evaluating recovery following carpal tunnel release surgery.

A variety of approaches have been previously tested for quantifying disability in work-related musculoskeletal disorders in the workplace, but with limited success. These include symptom questionnaires (4), and physical examination (5). Non-quantitative clinical tests, such as Phalen's and Tinel's signs are highly variable (6). Vibrotactile testing has been proposed as a test for CTS, but Fagius and Wahren (7) found intra-individual variation ranging from -59 to 58% compared to the first value measured. Electrodiagnostic methods such as nerve conduction studies (NCS) for predicting future carpal tunnel syndrome in asymptomatic workers were not found to be predictive of future hand and finger complaints (8). Electrodiagnostic testing, in conjunction with physical examinations, is currently considered the most accurate set of clinical tests for diagnosis of CTS. The obvious advantage of testing the median nerve directly using NCS is the absence of subjective reporting. Increasing electrophysiological deficits have been related to increasing CTS severity (9). Electrodiagnostic tests however are costly, time consuming and considered noxious by many.

The performance measures in our tests are based on functional activities performed in occupational tasks, such as repeatedly pressing a key or tactually inspecting a surface for a defect.

The sensory test involves detecting a computer-controlled gap on a highly polished surface. The psychomotor task is a rapid pinch and release task, utilizing specific muscles of the hand innervated by the median nerve, including the index finger and thumb. Previous studies demonstrated that the Wisconsin Test Battery could differentiate well-defined CTS cases from confirmed normal subjects (10). The purpose of this ongoing longitudinal study is to evaluate the Wisconsin Test Battery with industrial subjects that have been recruited from varying high-risk industrial settings.

METHODS

The study was conducted in the midwestern United States at five different industrial study sites. To date, 169 subjects (338 hands) have been tested, including 56 males and 113 females. A breakdown of the types of companies and the number of subjects tested is shown in Table 1. The mean age is 38.82 years (SD=9.36), and the range is 18-60 years.

Table 1.
Test Site and Subject Distribution

Company	Industry	Number of Subjects		
		Male	Female	Total
A	Plastics	8	12	20
B	Window Coverings	14	45	59
C	Turkey Processing	7	26	33
D	Publishing and Printing	2	17	19
E	Automobile Assembly	25	13	38
TOTAL		56	113	169

Subjects were recruited from departments and divisions that were identified by their employer as being high risk for carpal tunnel syndrome. This was confirmed by identifying the prevalence of CTS and the presence of risk factors for CTS (e.g., repetitive motion, extreme wrist postures, forceful exertions, etc.). All subjects were volunteers from the selected areas and participated with informed consent. Volunteers were paid their regular hourly salary for participating, and the majority of volunteers were tested during their regular shift time.

All subjects completed a symptom survey, which contained questions about symptoms in the upper extremities, the type of work performed and past medical history (e.g., diabetes, arthritis, thyroid disease, ruptured cervical disk, and renal failure). Information was gathered relating to specific symptoms in the hand such as numbness, tingling or pain, as well as frequency, duration and magnitude of the symptoms. Each subject also completed a self-reported hand diagram.

All subjects also underwent a physical examination of the upper limbs, shoulder and neck, which included general range of motion and strength assessment and provocative tests (i.e., Phalen's and Tinel's tests) for the median nerve. Positive response to Phalen's and Tinel's sign required pain or paresthesia in at least one digit innervated by the median nerve.

Nerve conduction studies (NCS) were also completed on both hands of the subjects. Testing consisted of median and ulnar transcarpal studies, median and ulnar motor studies and antidromic median digital sensory studies of the index finger.

An automated aesthesiometer measured tactile sensitivity while the index finger freely probed a tiny gap on an otherwise smooth surface. Gap detection sensory thresholds estimated the minimum width needed for detecting a gap on a smooth surface. Subjects were allowed five seconds to probe the metal plate prior to determining the presence or absence of a gap. Gap size was changed using a micropositioner and digital encoder, which was controlled by a microcomputer. As the gap size was changed, subjects responded verbally if they could detect a gap using the converging staircase method of limits paradigm. Contact force was controlled at 50 g. An auditory signal masked the noise of the motor so that subjects were not aware if movement of the plates had occurred. Both hands of all subjects were tested.

The rapid pinch and release test measured psychomotor performance in terms of speed and force control. An aluminum strain gauge dynamometer was pinched using the index finger and thumb. A pulp pinch strength test was first administered for determining maximum voluntary contraction (MVC). The subject was instructed to exert an MVC for five seconds and average strength data from the second to fourth seconds was determined. The objective of the rapid pinch and release psychomotor test was to pinch the dynamometer above an upper force level (F_{upper}) and then release below a lower force level (F_{lower}) as quickly as possible. Subjects performed the test using alternate hands, and completed two conditions of F_{upper} (10% and 20% MVC) for each hand; F_{lower} was fixed at 4% MVC.

The gap detection sensory test was administered first, followed by the rapid pinch and release psychomotor test. Subjects were allowed to feel the gap closed and the gap open at a fixed interval prior to testing. Both hands of all subjects were tested. Rapid pinch practice sets were completed prior to data collection. In half the subjects, F_{upper}=20% was collected first; in the other half, F_{upper}=10% was collected first. Alternate hands were tested to allow for recovery time.

The data were analyzed for observable differences between subjects who reported symptoms on the survey, NCS findings, and physical exam findings according to specified criteria. Positive symptom criteria were defined as symptoms reported at least monthly with an intensity of at least mild, and symptom location in the median nerve distribution and carpal tunnel area. For physical exam findings to be considered positive, one of the following criteria was required to be positive: Tinel's, Phalen's or tenderness over the flexor wrist compartment. Similar criteria have been developed for +NCS outcomes. The judgment of +NCS was not dependent on all NCS parameters being positive. Hands showing positive results in some NCS parameters and negative results in others were judged +NCS.

RESULTS

No statistically significant differences were observed for the gap detection thresholds or for F_{upper}=20% MVC pinch rate among subjects categorized by NCS, symptoms, or physical exam alone. Subjects having +NCS had an F_{upper}=10% MVC pinch rate of 4.62 pinches/sec, while the subjects having –NCS findings had an F_{upper}=10% MVC pinch rate of 5.50 pinches/sec [$F(1,223)=6.84$, $p=.01$]. Significant differences in F_{upper}=10% MVC pinch rate were also observed for subjects categorized by physical exam criteria [$F(1,233)=5.545$, $p<.05$].

The average change in pinch rate between F_{upper}=20% MVC and F_{upper}=10% MVC for the +NCS group was –0.0031 pinches/sec/MVC. In contrast, the change for similar conditions for the –NCS group was –0.1390 pinches/sec/MVC. This difference was statistically significant [$F(1,187)=4.953$, $p<.05$]. The groups classified by either symptom or physical exam criterion did not demonstrate significant findings.

Subjects were next classified based on combined physical exam (PE) and NCS results (Table 2). Statistically significant differences were observed between the +NCS/+PE group and the –NCS/–PE group for the F_{upper}=10% MVC pinch rate.

To be considered +CTS, a subject must have a +PE and a +NCS. In addition, the subject must also report positive symptom criteria in at least one hand to be classified in the +CTS group. Both the physical exam and NCS were required to be positive; if not, the subject was placed in the –CTS group. Results for this classification are shown in Table 3. The average gap detection threshold for the +CTS group was 0.26mm, while the –CTS group gap detection threshold was 0.17mm [F(1,285)=5.37, p<.05]. The F_{upper}=10% MVC pinch rate for the +CTS group was 4.26 pinches/sec, while the –CTS group had a pinch rate of 5.42 pinches/sec [F(1,223)=4.91, p<.05]. Change in pinch rate also demonstrated significant differences [F(1,186)=5.29, p<.05].

Table 2.
Mean Functional Performance Variables for PE (Physical Exam) and NCS (Nerve Conduction Studies). SD shown in parentheses.

	–PE –NCS Mean (SD)	+PE –NCS Mean (SD)	–PE +NCS Mean (SD)	+PE +NCS Mean (SD)
Gap threshold (mm)	.17 (.13)	.17 (.11)	.18 (.12)	.26 (.18)
20% Pinch Rate	4.75 (1.27)	4.29 (1.40)	4.55 (1.34)	4.51 (0.86)
10% Pinch Rate **	5.62 (1.62)	4.99 (1.68)	4.83 (1.01)	4.26 (1.65)
Pinch Rate Difference	-.1350 (.2965)	-.1558 (.2107)	-.0554 (.2261)	.1015 (.2316)

**p<.01

Table 3.
Functional Performance Variables for +CTS and –CTS groups

	–CTS Mean (SD)	+CTS Mean (SD)
Gap threshold (mm)*	.17 (.12)	.26 (.18)
20% Pinch Rate	4.65 (1.31)	4.51 (0.86)
10% Pinch Rate*	5.42 (1.60)	4.26 (1.65)
Pinch Rate Difference*	-0.1306 (.2772)	0.1015 (.2316)

*p<.05

DISCUSSION

When subjects were categorized as +CTS or –CTS, there were significant performance differences between groups for all of the functional variables of the Wisconsin test battery, with the exception of F_{upper}=20% MVC pinch rate. When subjects were categorized based on symptoms alone, performance on the functional variables did not differ between groups. When subjects were categorized based on NCS or physical exam findings, there were some differences between the groups, but it varied depending on the functional variable being tested. There were no differences in the gap detection thresholds or F_{upper}=20% MVC pinch rate among subjects categorized using NCS or physical exam alone. For F_{upper}=10% MVC pinch rate and change in pinch rate, subjects categorized using NCS demonstrated differences in performance. Subjects categorized by physical exam findings only demonstrated a difference in performance in F_{upper}=10% MVC pinch rate.

These results indicate that the Wisconsin test variables, F_{upper}=10% MVC pinch rate and change in pinch rate, were related to electrophysiological parameters regardless of symptoms. The Wisconsin test variable, F_{upper}=10% MVC pinch rate, was related to physical exam findings regardless of symptoms.

Unlike previous studies, where CTS patients in the electromyography (EMG) clinic seeking medical assistance were tested, the +CTS subjects were from a working population. It is likely that most of the +CTS subjects in the current study involve CTS symptoms that were less severe than our previous studies using EMG clinic subjects, many of whom were preparing for surgery. This makes it more difficult to categorize subjects as +CTS or –CTS. Physical exam findings and symptoms may not be at a level that indicates that the subjects should be placed in the +CTS category.

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THE ROLE OF ERGONOMICS IN REDUCING DISABILITY FROM LOW BACK PAIN

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ABSTRACT

Low back pain is a very old and a very common disorder. There is no known cause for the majority of low back pain episodes, although several risk factors have been identified. Efforts at preventing or reducing low back pain have not been very successful. However, there has been success in reducing the disability from low back pain through the use of ergonomics. Designing the job to fit the capabilities and limitations of people with low back pain allows them to continue normal working activities. Several examples of good ergonomic design are discussed.

THE NATURE OF LOW BACK PAIN

Low back pain is one of the oldest occupational health problems in history (1, 2). Low back pain afflicted the ancient Egyptians of 3500 years ago, and it was one of the major concerns of Bernardino Ramazzini, the founder of occupational medicine in the late 1600's. Despite this long history, low back pain has not enjoyed the medical advances that are found in other areas of medicine. For example, there have been dramatic reductions in small pox, polio, and tuberculosis, but there is absolutely no evidence that low back pain has declined over the years.

At any given point in time (point prevalence), 15% to 20% of adults experience symptoms of low back pain (3). The 1-month prevalence of low back pain is estimated between 35% and 37% (4). The 1-year prevalence is approximately 50% (5), and the lifetime prevalence is estimated between 60% and 80% (3).

Fortunately, 90% of patients with single episodes of low back pain return to work within six weeks (6). However, the pain continues for most patients. For those experiencing low back pain for the first time, approximately 70% will still report pain one year later (7, 8). The recurrence rate of low back pain is very high (6, 9, 10).

Up to 85% of low back pain has no definite etiology, and is classified as idiopathic or non-specific (11, 12). There are many theories, but no hard data. Pain producing pathology cannot be differentiated from simple aging changes (13). The main suspected source of most low back pain is in the outer anulus of the disc (13, 14, 15).

Although the cause of non-specific low back pain is unknown, several risk factors have been identified. Risk factors are associated with low back pain, but they are not necessarily the cause. The risk factors for low back pain include:

<u>Increasing age</u>: The prevalence of low back pain generally increases with age (2, 16). The intervertebral disc degenerates with age (17). The symptoms of low back pain change with age (18). And the disability from low back pain increases with age (19).

<u>Prior episode</u>: The probability of an episode of low back pain is greater after the initial episode; four times greater according to one study (20). Studies consistently find a history of back symptoms to be an indicator of future risk (13).

<u>Occupation</u>: The literature regarding the relationship between physical demands and low back pain is contradictory (16, 21). Sedentary workers also develop low back pain. It is unclear whether physical loading causes low back pain, or whether it precipitates or aggravates an existing, underlying condition (13).

<u>Time of Day</u>: The back is more vulnerable during the early morning hours (22). There is an increased risk of disc problems when bending forward in the early morning, primarily due to

increased fluid in the discs at that time (23). The probability of sprain and strain disorders is greater between 6 AM and 11 AM than at any other time of day (24, 25).

Genetics: There is a familial predisposition toward lumbar disc pain (26, 27). An identical twin study showed that genetics was more important than occupational factors in determining disc degeneration (28).

Obesity: There is a steady increase in back pain prevalence with increasing obesity, but most strikingly in the highest 20% of body mass index (29).

Smoking: The risk of low back pain increases steadily with cumulative exposure and with degree of maximal daily exposure (29).

DISABILITY FROM LOW BACK PAIN

There is no evidence that low back pain has decreased during the last 20 years (30). However, the disability from low back pain increased dramatically between the 1950s and 1970s without an increase in low back pain (31). One study showed that low back disability from 1957 to 1976 increased at a rate that was 14 times greater than the rate of population growth (32). In 1992, 14.9% of all Liberty Mutual workers' compensations costs were for low back disorders (33). Sixty percent of these costs were for indemnity (disability from time off the job). The major problem in industry today is low back disability, not low back pain.

Although low back pain may not be preventable at the present time, the good news is that we know how to reduce the disability from low back pain. Unlike low back pain, low back disability is closely related to the type of job performed. People with heavy manual jobs lose more time from work because of low back pain than people with lighter jobs. Ergonomic job design allows the employee with low back pain to continue working, or to return to the job sooner.

Contrary to popular opinion, the majority of people with low back pain continue to work, if the job permits it. About 2% of the American work force experiences disabling low back pain per year (34), as opposed to 50% of adults who report low back pain symptoms per year (5). According to most authorities, the resumption of normal working activities is the best possible therapy for people with low back pain (2).

THE APPLICATION OF ERGONOMICS

Ergonomics is the scientific study of human capabilities and limitations, applied to the design of jobs, tools, and environments. Since low back pain is so common, and since it is so difficult to prevent, workplaces must be designed for people with low back pain as well as for people without low back pain.

For example, workers with low back pain have difficulty bending forward. As Henry Ford said in the early 1900s, "The work must be brought to the man waist-high. No worker must ever have to stoop to attach a wheel, bolt, screw or anything else to the moving chassis." Excessive bending increases the probability of low back disability, and increases the chance of aggravating an existing disorder. One study showed that back disorders in an automobile assembly plant were associated with mild (20 – 45°) trunk flexion (odds ratio: 4.9), severe (>45°) trunk flexion (odds ratio: 5.7), and trunk twist or lateral bend (odds ratio: 5.9) (35).

Workers with low back pain also have difficulty handling heavy weights, especially when excessive forward reaching is involved. Object weight and horizontal reach, when combined to produce the moment, were found to predict the risk of low back disorders (odds ratio: 5.17) better than any other factor in the workplace (36). The accepted guidelines for determining maximum weights and forces consider forward reaching as an important variable (37, 38).

The basic ergonomic principle is to get things up off the floor. Heavier objects can often be handled with little stress if excessive bending and forward reaching are avoided. The following equipment is often recommended by ergonomists to reduce the stresses of bending and reaching in the workplace.

Benches: A simple bench is often recommended to reduce bending. Assembling and storing objects on a bench is preferable to assembling and storing objects on the floor.

4-Wheel Carts: Carts can often be used as a bench on wheels, assembling and transporting heavy and bulky objects.

Lift Tables: Scissors-type lift tables, powered by various means, are commonly used for loading, unloading, palletizing, and de-palletizing operations. Lift tables with a swivel top are particularly useful for palletizing and de-palletizing operations.

Hoists and Balancers: These devices are particularly useful for moving heavy objects from one location to another.

2-Wheel and 4-Wheel Hand Trucks: Hand trucks have been used for years to move heavy objects. Some hand trucks have been designed specifically for moving heavy and bulky objects up and down stairs and curbs.

Conveyors: Roller conveyors, belt conveyors, and air tables are often the choice for transporting objects from one location to another.

Sit-Stand Workstations: For jobs which require prolonged sitting, the sit-stand workstation allows the employee to change from a sitting posture to a standing posture (and vice versa) without interfering with the job. This is important for people with low back pain who cannot maintain the same posture for long periods of time.

Management is often reluctant to purchase special equipment because of the costs involved. However, committing capital to redesign jobs can often be a wise business investment. Decreases in compensation costs and increases in worker performance will return the cost of the initial investment over time. Determining the "payback period" will help convince management of the cost effectiveness of redesigning jobs.

The reduction of bending, reaching, and handling heavy objects also applies in the home, before the work day begins. The weight of the torso and the head can be considered as heavy objects to a person with low back pain. Ergonomics recommendations for use in the home include the following:

Stand-Up Desks: Similar to the sit-stand workstation, stand-up desks have been used for many years by famous people such as Thomas Jefferson, Benjamin Franklin, Henry Wadsworth Longfellow, and Winston Churchill. The top of a high dresser can also be used.

Chairs: Chairs with arms help a person with low back pain move into and out of a chair with less stress. A good lumbar support is helpful in maintaining a straight back while sitting.

Suitcases: One of the great innovations in suitcase design was the vertical suitcase with wheels and a retractable handle. The result is reduced bending and less stress from carrying the bag for long distances.

Long-Handled Dust Pans: Long-handled dust pans with brooms have been used commercially for many years. They are just as applicable in the home.

Changes in early morning behavior have been shown to reduce chronic low back pain. Since the back is more vulnerable in the morning because of increased fluid levels and pressures in the intervertebral discs, it is important to reduce bending as much as possible. A recent study (a randomized controlled trial) investigated 60 subjects with chronic low back pain (22). Pain and disability were significantly reduced by simply not having them bend during the first hour of the day. It is not easy to change behavior. However, for those willing to try, the reduction in pain and disability can be substantial.

SUMMARY

Ergonomics is a powerful and cost effective tool in reducing disability from low back pain. Ergonomic job design allows the employee with low back pain to continue working, or to return to the job sooner. This is truly a win-win situation. The employee wins by being able to continue normal work activities, and management wins through lower costs and higher productivity. Therein lies the beauty of ergonomics.

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ERGONOMICS AND WORKPLACE ACCOMMODATION TO IMPROVE OUTCOMES IN A LARGE WORKERS' COMPENSATION SYSTEM

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ABSTRACT

Work-related upper extremity disorders (WRUEDs) account for a significant proportion of workers' compensation claims, lost time, and indemnity and health care costs. Failure to implement work site accommodations may be a factor contributing to delayed functional recovery and relapse. Nurse case managers often participate in the medical management and return to work process for injured workers receiving workers' compensation benefits. As such, this group of providers could play a strategic role in the actual implementation of workplace accommodations. This study examined the feasibility of providing instruction to nurse case managers in ergonomic principles, work site risk factor identification, and implementation of a systematic approach to accommodations. The intervention was directed at facilitating return to work in claimants with a WRUED. Preliminary results indicate high nurse ratings for a 2-day training seminar in terms of perceived ability to implement an ergonomically based workplace accommodation intervention. Results also indicated implementation of 2.7 accommodations per study case in the following year. These preliminary results demonstrate that case managers can be instructed in principles of ergonomics and that these principles are actually applied when included in a systematic step wise procedure to facilitate work site accommodation. Subsequent analyses will determine the actual impact of this approach on work, health and economic outcomes.

BACKGROUND

Work-related upper extremity disorders account for a high proportion of claims, lost time, and indemnity and health care costs. These disorders have been particularly difficult to manage clinically and administratively, and reports indicate that a relatively large proportion of cases experience delayed functional recovery. A study conducted on Washington state workers' compensation claimants indicated that carpal tunnel syndrome was associated with a longer disability duration than back disorders and all other injuries (1). Data on the Federal workforce revealed that for those carpal tunnel syndrome cases with time loss, the average days lost approximated that of back cases (2). While the prevalence of upper extremity disorders is not as high as back pain and a large percentage of cases receive medical care only (i.e., no indemnity), the morbidity can be significant. The impact of these disorders on lost time, indemnity and health care costs and quality of life requires innovative efforts to improve outcomes.

Case management has played an increasingly important role in the treatment of employees receiving workers' compensation benefits, although such services are often limited to monitoring the claims process and surveillance of the medical treatment. Proponents of case management argue that these procedures reduce costs related to health care and indemnity, particularly in the short term. However, there are no large scale trials of the effects of case management on broader outcomes of importance to workers' compensation systems such as injury recurrence, worker perceived quality of medical and case management, symptoms, function, and worker perception of health and well-being.

Typically, case management procedures for work related upper extremity disorders (WRUEDs) follow the traditional claims and medical management model, despite data from a number of sources indicating that these disorders are influenced by a variety of medical, ergonomic and psychosocial factors (3, 4). An integrated case management approach that systematically addresses workplace ergonomic risk and other factors should reduce costs while simultaneously improving the quality of care provided to injured workers.

RESEARCH QUESTION

The purpose of the overall study is to determine whether case management that targets medical, ergonomic, workplace, and psychosocial factors in an integrated format (i.e., Integrated Case Management [ICM]) results in improved outcomes in contrast to conventional case management approaches that focus on medical management only. This paper will present data on the feasibility of training nurse case managers in the principles of ergonomics and their application to workplace accommodation within the case management process. The results of this training, in terms of the frequency and type of actual workplace accommodations, will also be described.

METHOD

Case managers. Case managers were randomly selected from the active lists of registered nurses under contract to the US Department of Labor's workers' compensation program to provide services to injured workers in the following metropolitan areas: Washington/Baltimore, Chicago, Boston, Philadelphia, Los Angeles/San Diego, San Francisco, Seattle, and Dallas/Fort Worth. Incentives for participation included continuing education credits from the Case Management Society of America and the opportunity to learn new case management skills.

Injured workers. The claimants in this study are Federal civilian workers with adjudicated claims for work-related upper extremity disorders who are randomized into two groups: Integrated Case Management (ICM), or Usual Care (Control). Eligible claims include single claims/single cases (no past claim/case in prior two years) with an ICD-9 diagnosis that falls into the ANSI Z365 classification of work-related upper extremity disorders. Only those cases adjudicated within 30 to 90 days from the initiation of lost work time will be included.

ICM nurse training. Nurse case managers were instructed in the ICM intervention. The nurses were trained in each of eight components of the ICM intervention in a 16-hour two-day training workshop. This workshop included a combination of didactic presentations, case simulations and hands on exercises. ICM nurses were informed at the initial training session that project staff would be available by telephone, e-mail, and internet site throughout the course of the project to provide a sounding board for discussing strategies for individual cases, provide suggestions, and receive feedback. The intervention included several additions to the case management program currently in use:

Semi-structured interview. Nurses were provided instruction and given opportunities to practice administering a semi-structured interview technique to be used with WRUED claimants. The interview was designed to obtain useful information about a claimant's background, current medical status, medical history, work, prior workplace accommodations, non-work-related activities, and psychological distress.

Problem-solving. Nurses were trained in a 6-step problem-solving technique (5). Using this approach, nurses review with the claimant past attempts to solve problems, including both effective and ineffective problem-solving strategies. Then, case managers introduce and teach the problem-solving process to assist the worker to more effectively address challenges related to: medical management, symptoms, function, reasonable accommodations and return to work.

Work site ergonomic assessment. Nurses are trained to conduct a work site analysis using a standardized protocol that includes a self-report measure of exposure, a brief workstation checklist, and a measurement of workstation factors that may contribute to increased fatigue, discomfort and pain. Ergonomic factors that contribute to awkward postures, excessive repetition, increased force, contact stress, glare, temperature extremes, work organization, and potential high risk work style are identified.

Work site accommodation process. Nurses are trained to generate a plan for the provision of reasonable accommodations targeted at elimination and/or reduction of ergonomic risk factors. Discussion with and input from the worker, immediate supervisor, and other agency representatives regarding possible accommodations and their schedule for implementation is a key component. Purchase of appropriate assistive devices/technologies are pursued.

Measures:

Nurse ratings of the training seminar. At the conclusion of the 2-day training, case managers rated their level of confidence from 1 to 10 (1 = no confidence, 10 = extreme confidence) on their ability to use the two primary components of the ICM program: ergonomics and problem solving. Also, case managers completed an evaluation of the 2-day training seminar, including the following questions on a scale of 1 to 5 (1 = least agree, 5 = most agree):

- Met my expectations?
- Able to use this information on my next case?
- Have a clear understanding of my role?
- Have a working knowledge of the ICM program?
- Physical facilities conducive to learning?

Self-reported ergonomic exposure. Self-reported ergonomic exposure was assessed by the Job Tasks section (38 items) of the U.S. Air Force Job Requirements and Physical Demands Survey (JRPDS) (6). Factor analyses of the JRPDS have shown evidence of seven factors that account for 56.4% of the variance in self-reported ergonomic exposure. The reliability and validity of the Job Tasks section of the JRPDS and the trunk postural strain subscale has been demonstrated in previous studies. Internal consistency is high (Cronbach's alpha = 0.88), and test-retest reliability (2-3 week time lapse) has indicated a moderate degree of stability ($Eta^2 = 0.57$; $r = 0.67$, $p < 0.01$).

Frequency and types of accommodations. From case managers' monthly progress reports in the first year of the study (the first 27 ICM claimants recruited), work site accommodations were identified, categorized as administrative or equipment-related, and counted.

RESULTS

Recruitment of participating case managers. Of a total pool of 128 registered nurse case managers contracted to the U.S. Department of Labor's workers' compensation program in the seven study sites, 79 (62%) were randomly chosen and invited to participate. The only incentives offered were continuing education credits from the Case Management Society of America (CMSA) and the opportunity to learn new case management skills. Of those contacted, 61 (77%) were recruited and 56 (71%) ultimately participated in the training seminars. The reasons for non-participation (n = 23) were as follows: Too busy = 5 (22%); Scheduling conflict = 10 (43%); Illness = 3 (13%); Not interested = 2 (9%); Unresponsive = 3 (13%).

Evaluations of case manager training. Overall, evaluations of the training were high (between 4 and 5), and confidence ratings were moderate (between 6 and 8). The mean of evaluation ratings was 4.4 ($SD = 0.3$). The mean "ergonomics" confidence rating varied from 2 to 10 ($M = 7.5$, $SD = 1.1$). The mean "problem solving" confidence rating varied from 1 to 10 ($M = 7.3$, $SD = 1.8$).

Demographics of injured workers. In the first 7 months of the study, 218 workers with accepted claims for WRUEDs were contacted by mail and asked to participate in the ICM study. Ninety-five (44%) agreed to participate. Participants were 27 male and 68 female Federal workers. Ages ranged from 26 to 81 ($M = 47$, $SD = 12.6$). At the time of recruitment, 36 percent were working (limited or modified duty) and 64 percent were not working. Of those working limited or modified duty, the majority (75%) were working 40 hours per week. Sixty-five percent of the participants reported at least one surgical intervention for their upper extremity symptoms in the past. A comparison of volunteers and non-volunteers showed no statistically significant differences in age, state of residence, employing agency, type of accepted health condition, number of accepted conditions, time to process claim, or frequency of controverted claims. There was a difference in gender, with women being under-represented in the volunteer group versus the non-volunteer group.

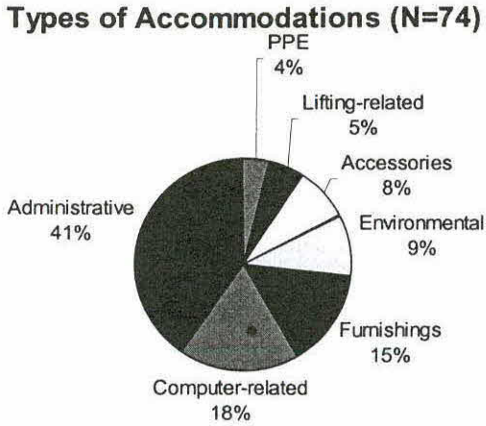
Self-reported ergonomic risk factors. Participants reported a mean score of 58.6 ($SD = 21.4$) on the JRPDS, the self-report measure of ergonomic risk factors. To provide a frame of reference, this mean score could be obtained by endorsing that 20 risk factors were present 2-4 hours per day. The most frequently reported risks were: (a) holding my arms in front of or behind my body; (b) my wrists are bent; and (c) performing repetitive tasks/movements.

Reported accommodations. A review of the first 27 ICM cases from case manager progress reports indicated that 74 accommodations were implemented. Accommodations per case ranged from 0 to 9 ($M = 2.7$). Types of requested accommodations are shown in the following figure.
Equipment-related accommodations included the following:

Chair (7)	Workspace (3)	Splint (2)
Headset (5)	Foot rest (2)	Desk edges (1)
Keyboard (4)	Arm support (2)	Copy holder (1)
Modified mail bag (4)	Mouse (2)	Nonvibratory gloves (1)
Monitor (3)	Lighting (2)	Voice activated software (1)

Administrative accommodations included the following:

Modified duty (18)	Room temperature (2)
Breaks (6)	Change of hours (1)
Help from others (3)	



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EMPLOYER RESPONSES: A KEY FACTOR IN ACHIEVING REHABILITATION OUTCOMES

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ABSTRACT

As the workforce ages, more of those who are working will have chronic health conditions. Employer policies, attitudes, and actions in response to these conditions are important determinants of disability. Recent studies have shown that group health insurance coverage, disability management programs, attitudes and responses to employee reports of illness, nature and timing of disability prevention interventions can significantly affect health-related time lost from work. Accommodations can be highly effective means of disability prevention if they are appropriate for the worker, health condition, and workplace. Rehabilitation professionals can effectively advocate for positive changes, based upon a thorough understanding of the reasons for current policies and practices.

INTRODUCTION

There are many reasons for employers, insurers, legislators and workers to identify methods of preventing work absences due to illness. Health-related absences from work account for over 650 million days each year in the American workforce, with an estimated total cost of over $300 billion dollars (Brandt and Pope, 1997). Indirect costs, such as losses in productivity, administrative and retraining expenses may be three times as large as the direct and easily measured costs (medical care and wage replacement). Cases with prolonged work loss represent a small proportion of all workers' compensation cases, but account for a majority of the costs (Snook, 1988). In work-related injuries, once absence from work exceeds six months, the probability of ever returning to work becomes quite small (Krause, 1994). Those with unemployment due to illness suffer significant financial, emotional, and social effects, and represent a significant, long-term burden on the social welfare system.

Employer policies, attitudes, and actions are significant determinants of employment in persons with health conditions, especially those conditions that directly affect ability to work (Shrey and Lacerte, 1995). Employers often provide health insurance and may direct workers to systems of health care. Organizational policies and procedures include responses to employees who report health problems, management of resulting disability, accommodation and other efforts to facilitate return to work, compensation and retention of employees while on sick leave, and measures to prevent disability.

We present evidence for the influence of organizational policies and managerial responses on the work status and rehabilitation outcomes of employees with health conditions, and offer suggestions for rehabilitation professionals and researchers who desire to achieve better outcomes. Our focus is on the factors that relate directly to the employer, especially where modification of responses to employee illness and injury show promise in decreasing lost time. Other factors also have a significant impact on work loss, including sociodemographic and job factors, type and severity of injury, prior chronic illness and health status, psychological factors, level of compensation, and economic conditions; these issues have been reviewed in detail elsewhere (Deyo, 1987; Milhous, 1989; Burton, 1995).

THE HEALTH OF WORKERS AND WORK STATUS

As the workforce ages, and progress in medical care enables survival of those with illnesses that were once fatal, there are more employees on the job with chronic health conditions. Several national surveys provide data on the types of conditions that affect ability to work, and effect on work status. The National Health Interview Survey (NHIS) has been conducted as a stratified, cross-sectional survey of over 40,000 Americans each year since 1957. Detailed questionnaires ask about health, functional limitations, medical care, and socioeconomic status. NHIS data from 1997 on those aged 18-65 estimated that 36 million Americans are limited in some way in their ability to work due to a health condition. The most common conditions reported are included in Table 1. The prevalence of health conditions and work limitations increases by age and by lower socioeconomic status.

TABLE 1
1996 National Health Interview Study

1996 National Health Interview Study, Rates/1000 men in the US (adjusted)						
Age	<45 years		45-64 years		>65 years	
Family Income	$10-20K	>$35K	$10-20K	>$35K	$10-20K	>$35K
Arthritis	39.4	16.7	378.3	193.0	445.7	395
Visual Impairment	23.9	14.4	82.3	38.1	123.1	72.6
Hearing Impairment	34.9	29.2	179.6	117.0	294.2	206.4
Diabetes	12.9	7.5	93.1	36.5	103.2	82.6
Heart Diseases	50.2	31.7	205	106.9	284.4	231
Chronic Bronchitis	51.7	50.2	78.8	50.0	75.3	60.1
% activity limited	15.2	6.3	41.5	14.2	42.7	22.9
% limited in ability to work	11.5	4.0	33.7	8.8		
% unable to work	6.3	1.3	22.0	3.5		
Bed days/year.	8.5	3.1	18.1	3.9	13.4	8.0

Those with chronic health conditions and some limitations in ability to work but who are still employed represent successful outcomes, inasmuch as a chronic health condition did not result in loss of employment. However, a somewhat different perspective emerges from the detailed 1998 National Organization on Disability / Harris survey of Americans with disabilities (Risher and Amorosi, 1998). This survey documented that the types or jobs and level of income available to persons with disabilities was quite limited in comparison with others who have comparable skills and experience. Of those out of work because of their disability, 37% felt that they could be working, but a suitable job was not available or had not been offered. Over half of those who were working (58%) at the time of the survey had been refused jobs because of a medical condition, and

30% had encountered negative attitudes about their condition in the workplace. Thus, these surveys indicate that successful employment of an aging and increasingly disabled workforce will require more accommodations, health care services that focus on preventing job loss, positive employer and co-worker attitudes, worker training, and other interventions.

ORGANIZATIONAL POLICIES

There are various organizational policies which can affect employees' psychological, behavioral, and physiological problems as well as organizational productivity and image. For instance, restriction in access to health care benefits can lead to inadequate treatment and thus greater disability for certain conditions. Mental health services have been significantly affected by aggressive efforts to control medical costs, with reductions in service utilization approaching 30% in some instances through implementation of deductibles, copayments and restrictions. Until recently, the effects on productivity have not been measured. A recent study reported a significant relationship between decreases in mental health services utilization due to restrictions and increases in sick days. Ironically, savings in mental health service costs were completely offset by increases in lost work days and medical costs (Rosenheck et al, 1999). Thus, management choices regarding health care coverage can have a direct impact on lost work days.

In a survey of human resource directors of Michigan industries, Habeck (1993) found that a lower company-wide incidence of lost workday cases and fewer workers' compensation claims per worker was associated with several organizational attributes. These included safety diligence (housekeeping, equipment maintenance, timely accident investigation and remediation), safety training, and proactive return-to-work programs (joint labor-management design of alternative duty placements; creative placement and accommodations; and timely utilization of internal and external disability management resources). These findings suggested that sensible policies, such as positive initial responses to work injury reports, may reduce lost time per injury. It should be noted that the above relationships may well be underestimated because aggressive safety programs that include disincentives linked to reported injury rates can result in significant under-reporting of injury incidences (Pransky at al, 1998).

Though many studies have examined various predictors for return-to-work outcomes, none have directly assessed negative managerial responses (Valat, 1997), although their importance has been recognized by several researchers (Frymoyer, 1992). The occupational stress literature has consistently shown the linkage between high supervisory social support and lower anxiety, depression, somatic symptoms and disability in workers (Jex, 1998).

We recently reviewed data from a retrospective study of work-related injuries that resulted in workers' compensation claims (Pransky et al, 2000). Respondents were asked to complete a detailed, validated questionnaire one year after their injury. The questionnaire included work history, job satisfaction, medical and psychological factors, medical care, satisfaction with care, employers' initial response and accommodations, and functional and vocational outcomes. Four questions with a yes/no format (i.e., blaming the employee, angry because the employee was off work, did not believe the employee was hurt, and did not want the employee to file a claim) were used to assess the initial response of the supervisor to the report of a work-related injury. The mean number of negative responses significantly differed by amount of time lost from work due to the injury ($F = 5.32, p < 0.05$), while statistically controlling for possible confounding factors (e.g., job satisfaction, type of work, type of injury, etc.). Those respondents who lost less than one week of work reported a mean of 0.53 negative responses from their supervisor, while those who lost a week or more of work reported a mean of 1.04. Respondents who had never returned to work reported a mean of 1.53 negative responses.

A report of an intervention at a large manufacturer indicates that supervisor responses can be modified, with positive effects (Fitzler, 1982). The main focus of this multi-component intervention was to facilitate positive management responses to reports of pain, replacing confrontation and denial with acceptance and accommodation. This was based upon observations that supervisor-subordinate interactions are important determinants of a worker's sense of well-being, injury reporting, and the key role of supervisors in the return-to-work process (House, 1981). The program succeeded in achieving a 90% reduction in back injury claims and a 50% reduction in lost work days. Similar interventions have resulted in an increase in injury reporting, but a significant decrease in lost work days, as the primary measure of success (Melton, 1983; Tomer, 1984).

EMPLOYER ACCOMMODATIONS

A recent review of the value of modified work programs in achieving reductions in work absence has concluded that they are successful in those with short-term as well as long-term disabilities (Krause, 1998). Modified work programs were associated with twice the return-to-work rate and half as many days of lost work in disabling injuries, and savings of 8 to 90% of baseline workers' compensation costs, compared with injured workers employed in companies without these programs. However, the authors noted variations in definition of modified duty, types of programs, study designs, and confounding factors that precluded formal comparisons through meta-analyses. Programs ranged from light duty jobs to job coaching and ergonomic equipment modification. Only one study represented a randomized, controlled trial; most reports described a modified duty program that included other concurrent interventions. There was considerable inconsistency in reported outcomes; about half of the studies reviewed measured return-to-work within the period of follow-up as a categorical variable, and a few evaluated time to return to work. Some studies reported attributed cost savings, but only one study reviewed attempted to conduct a formal cost-benefit analysis.

How employers respond to requests for accommodations varies widely. Less than half of those who reported some work limitation in the NHIS data were totally unable to work, suggesting that some accommodations are frequently made to allow employment for those with illnesses that affect work capacity. The NAD survey provides some insight into the strategies that enable employment; over half reported changing jobs, employers providing alternative work placement or job modifications, retraining, and other approaches. Knowledge of available programs may be a significant barrier to successful accommodation; in another study, less than a fourth of disabled persons were aware of their eligibility for a program that facilitated a trial of supported work resumption (Hennessey, 1994). However, the NAD survey indicated that many of those surveyed could be working if proper accommodations were available. Of those out of work, 28% reported that special equipment or devices to communicate with others or get around the workplace would enable employment, and 24% reported that absence of adequate transportation to and from work was a major barrier to employment.

In our data on injured workers reviewed above, the presence or absence of employer accommodations was not associated with length of work absence; however, there was a statistically significant association between employee satisfaction with accommodations and length of disability, as well as the frequency of re-injury. The most common complaint was that the work provided under the guise of light duty was actually no less physically demanding than the employee's regular job. Thus, the act of offering accommodations may not be sufficient by itself. In contrast, others have suggested that accommodations can lead to prolonged partial disability and a sense of vulnerability, and argue for a prompt return to full duty in many cases (Burton, 1997). Ergonomic interventions that change jobs to decrease levels of biomechanical stress offer an advantage over temporary accommodations by providing a permanent solution and reduction in risk for future disability. This approach may be most important in conditions such as low back pain and chronic illnesses, where recurrence is common and recovery of physical functional capacity may not occur.

DISABILITY CASE MANAGEMENT AND EARLY INTERVENTION

Several authors have argued for early recognition of the potential for prolonged disability and the role of early intervention, as delays in recognizing the onset of potentially prolonged work absence can lead to adverse outcomes (Galvin, 1985). One successful approach educated workers about the causes and expected course of low back pain, and the importance of maintaining activity, including work (Symonds, 1995). The importance of integration is often emphasized, as coordination among external medical providers, internal safety and ergonomic resources, and disability managers can lead to much smoother and more successful work transition. Prompt and continuous communication with employees after disability has occurred is necessary to maintain the worker's affiliation with the workplace (Stultz, 1995). Even when an ideal program is in place, some workers will be unable to resume employment at their former employer. In these cases, a proactive approach that recognizes the need to look elsewhere for employment can achieve success, as long as expectations are reasonable and appropriate vocational rehabilitation is instituted.

SUMMARY – RECOMMENDATIONS FOR REHABILITATION PROFESSIONALS

In an excellent review of opportunities for employer responses to improve outcomes, Stultz (1995) suggests that success can occur only if there is a culture of positive responses to employee reports of health conditions affecting ability to work. Rehabilitation professionals are often consulted by employers on disability issues, and thus have a unique opportunity to help develop and implement solutions that can begin with attitudinal change. Success is based upon a clear understanding of the workplace environment, labor-management relationships and motivations, rationale for existing policies and actual procedures, and specific types of injuries and illnesses that lead to disability in the workforce. Although an ideal approach can be easily articulated, the consultant must take an integrated approach (e.g., ergonomic, rehabilitation, organizational behavior) and apply a clear understanding of reasons for current procedures, and chart a course that will facilitate a gradual transition to and acceptance of a new paradigm. Persuasive arguments for change may be drawn from case histories, a review of accident and disability data, and examples of success in other industries. Few published reports of successful programs contain adequate controls, blinded assessment of outcomes, or report on a single intervention, evaluated in an unchanging environment. However, the magnitude of reported improvements strongly suggests that the interventions described here, especially appropriate accommodations, can have a significant and sustained impact.

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ERGONOMIC JOB DESIGN TO ACCOMMODATE AND PREVENT MUSCULOSKELETAL DISABILITIES

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ABSTRACT

Work-related musculoskeletal disorders (MSDs) account for a major portion of the cost of work-related injury and illness in the United States. Many of these injuries and illnesses lead to temporary or permanent disability. It is generally accepted that the incidence of MSDs increases when the demands of the job exceed the capabilities of the worker. As the work force ages and physical capabilities decline, it is anticipated that many more Americans will file for disability due to musculoskeletal disorders because they are unable to meet the demands of the job. In order to prevent these disabilities and to accommodate a wider range of the workforce, job demands will have to be reduced so that a larger fraction of the population will be capable of working. Providing engineering controls or alternative work arrangements allows for accommodation of workers with a wide range of capabilities and can assist in rehabilitation and early return to work following injury.

INTRODUCTION

Work-related musculoskeletal disorders (MSDs), such as low back pain, tendinitis, hand arm vibration syndrome and carpal tunnel syndrome, account for a major component of the cost of work-related injury and illness in the United States. The costs associated with work-related musculoskeletal disorders are estimated to be as high as $100 billion annually, with occupational low back pain accounting for an estimated 34% of the total costs of all occupational injuries and illnesses combined (1). The problem is large, both in health and economic terms. Disability arising from these occupational disorders is a serious concern. As many as 16.5% of the adult population in the United States is disabled, and musculoskeletal disorders are the most frequent type of disability. Although a number of MSD symptoms, such as low back pain, usually abate within about six weeks of onset, a small percentage develop into chronic disorders that will end in temporary or permanent disability. Disability is defined as a limitation in the amount or kind of gainful work that can be performed because of a chronic condition or impairment (2). Disability is classified according to the severity of the disorder and the time of functional limitation. Temporary disability usually lasts a few months, whereas permanent disability may last a lifetime. Partial disability describes cases in which the worker can perform part of the job functions, but not all. Total disability describes cases in which the worker can not perform the job functions.

There is strong evidence that occupational exposure to physically demanding and/or highly repetitive jobs, even for short periods of time, can lead to acute MSDs, which in some cases can lead to temporary or permanent disability (3). It is also likely that long term occupational exposure to physically demanding jobs leads to disability for older Americans in post-retirement years. For example, osteoarthritis, rheumatism, and other chronically disabling diseases affect millions of older Americans, many of whom were exposed to repetitive and physically demanding jobs during their working careers.

PREVENTION

Ergonomics, the science of designing jobs to fit workers, provides the best opportunity to prevent disabling musculoskeletal disorders, in both near and long term. Although the objectives of an ergonomics program are to improve efficiency, quality and productivity of the work being done, and to reduce risk of injury or illness to the workers doing the work, a natural outcome of an ergonomics program will be to increase the size and diversity of the pool of workers who can safely perform the job. Ergonomics examines the physical demands of the job, and seeks to reduce them so that they do not exceed the capabilities of the worker. A wide range of tools is available for estimating the physical demands of jobs. These tools consider the various risk factors for MSDs, such as the applied force required, weight lifted, frequency of activity, posture, duration of exposure, dynamic requirements, etc. Studies have shown that, in order to prevent MSDs, the demands of the job should be reduced to a level that would be acceptable to 75% of healthy workers (4).

Another significant concern for prevention of disability from MSDs is the aging worker population. The Bureau of National Affairs estimates that between 1986 and 2000, the number of workers aged 35 to 47 will increase by 38%, and the number between ages 48 and 53 will jump 67%. Estimates from Japan indicate that 25% of its population will be older than 65 years by the year 2020. Research indicates that older workers will experience significant decrements in physical capacity, psychomotor skills, and neurobehavioral function. Age also affects how muscles and joints respond to applied loads. For example, aging can cause degeneration or weakening of the tissues that can reduce tissue capacity to withstand applied loads. Also, due to changes in the retirement age for social security, workers are continuing to work for more years, especially in lower paying and more strenuous jobs. In order to prevent disabilities in these older workers, job demands will have to be reduced to levels that would be significantly below what would be acceptable for more fit, younger, and stronger workers.

There is additional concern about the problem of obesity and lack of fitness or conditioning for many U.S. workers. In a recent study of obesity, it was found that the prevalence of obesity increased from 12.0% in 1991 to 18.0% in 1998 (5). According to the authors, it is rare that chronic conditions, such as obesity, spread with the speed and dispersion characteristics of a communicable disease. It is interesting to note, however, that this study also found that self-reported physical activity did not change significantly over the same period. Recent media reports have claimed that almost every American will be obese by the year 2023 if current trends in the prevalence of obesity continue. Workers who are overweight and have physically demanding jobs are at significantly increased risk of an MSD. For example, when an overweight individual bends over to lift a load, the forces created in the spine are greater than they would be for an individual of normal weight, because of the additional biomechanical forces need to lift the extra body weight. These additional musculoskeletal forces could conceivably turn a safe job into a high risk job for an otherwise healthy individual. Also, being overweight, older, and physically inactive has been shown to increase risk for carpal tunnel syndrome (CTS) (6).

A number of studies have shown that prevention efforts are best achieved by properly designing the work activity using engineering approaches. The engineering approach involves modifying the tasks and tools using ergonomic principles to reduce the effects fo biomechanical stress. Ergonomic design examines the job layout and work process or procedure to reduce potentially high risk movements (e.g., bending and twisting), awkward postures, high forces, and repetitive motions. The engineering approach is desirable because it seeks to make safe work practices a natural result of the tool and worksite design. Although engineering approaches are preferred, administrative controls also have been used to prevent MSDs. These approaches include education and training programs, worker placement, worker strength or fitness training, and the use of protective equipment.

ACCOMMODATION

Ergonomics can also play a crucial role in accommodating disabled workers in the workplace. In many cases, disabled workers can perform a moderate level of physical work, but the job requirements must be sufficiently reduced to meet their capabilities. Many jobs that exist in industry today are designed so that only a small percentage of the most capable workers can safely perform them, thereby eliminating most disabled workers. In order to accommodate disabled workers, job demands will have to be significantly reduced to levels that would be acceptable to nearly all healthy workers.

Ergonomic design also must recognize that disabled workers do not function the same as healthy workers. They use different body mechanics, including modified kinematics (body posture and movement velocity and acceleration) and kinetics (muscle and joint forces and patterns of muscle activity). Movement patterns are typically altered when a worker becomes injured. Disabled workers typically move slower, and have less flexibility and strength; and their muscle coordination may be significantly altered. All of these changes can modify the biomechanical loads on the soft tissues of the body and increase risk of injury at equivalent levels of externally applied loads.

The 1991 Americans with Disabilities Act (ADA) mandates that employers with 15 or more employees make reasonable accommodation to allow qualified workers with disabilities to participate in the workforce. According to ADA compliance records, low back disability cases represent one of the most frequent reasons for a worker filing an ADA case.

REHABILITATION and RETURN-TO-WORK ISSUES

Research has shown that getting workers back to work after an injury is the best approach for preventing permanent disability. The most effective return-to-work programs provide a wide range of employment options that include availability of jobs with varied physical and mental demands, modified or reduced work requirements, alternative work schedules (e.g., part-time work and job sharing), as well as adaptive or redesigned equipment. Work organizational changes may also be effective in modifying the job requirements or reducing the work demands. These can include slowing down the pace of work, changing the process, job rotation, or job enlargement.

PSYCHOLOGICAL and SOCIAL ISSUES

It is recognized that psychological and social factors interact with physical factors to increase an individual's risk of developing an MSD. A disabled individual may be exposed to a significantly different psychological and social environment than a non-disabled individual, even though the work is similar. Factors such as supervisor and co-worker support may differ for disabled individuals, and the social stigma of disability may affect a worker's ability to cope with interacting factors. Thus, additional efforts should be made to ensure a sound organizational environment for disabled workers.

SUMMARY AND CONCLUSIONS

Disability from work-related MSDs is a significant and costly problem to society. Preventing first occurrences of MSDs is preferred. The Americans with Disabilities Act, however, requires companies to make reasonable accommodation for disabled workers. Due to sociological and demographic variables, such as aging and increasing retirement age, it is anticipated that more older workers will be required to continue working, especially in low paying and physically demanding jobs. For this reason, it is expected that disability will increase in the future. Therefore, it is crucial to increase efforts to prevent disability and to accommodate workers who have sustained injuries by providing more flexible workplaces in which a wide range of individuals can participate.

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