RESNA '90

Capitalizing on Technology

For People With Disabilities

Proceedings of the 13th Annual Conference

Washington Hilton & Towers

Washington, D.C.

June 15-20, 1990

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Jessica J. Presperin, OTR/L, MBA
Editor

Judith E. Harkins, PhD
Conference Chair

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Foreword

RESNA has experienced many positive changes over the past several years with the publication of its journal, **Assistive Technology**, the beginning of a project of technical assistance to states under the Technology Related Assistance Act, the offering of regional conferences, and the expansion of our national conference.

The RESNA 13th Annual Conference, held in Washington, D.C., highlights the role that public policy can play in improving the availability of technology and stresses technology as a resource to be exploited for its powerful effects in the lives of disabled people.

One of the traditional strengths of RESNA's annual conferences is that the proceedings are made available to participants during the conference. This feature is somewhat unique among conferences, and we believe it improves the quality of interaction during our scientific sessions. The proceedings also provides our multifaceted field with a central core of literature describing the year's work in research, development, pubic policy, and service delivery. By referring to the RESNA proceedings, one can get a good cross section of information on many technologies for people with many types of disabilities.

We congratulate the participants in this RESNA conference who are making such a contribution to the literature on rehabilitation and assistive technologies.

Richard A. Foulds, PhD
President

Judith E. Harkins, PhD
Conference Chair

Preface

RESNA continues to change with the times and it seems all too appropriate to start off the decade with the annual conference in Washington, D.C. With the passage of the Technology Related Assistance Act, the recent issues with the Disabilities Act, and many other legislative activities affecting RESNA, it's exciting to be where all the action is.

Once again, Tony Langton and the Meetings Committee created this dynamic conference. Susan Johnson Taylor did a terrific job at organizing an impressive list of instructional courses and morning seminars. The variety of topics (new technology, theory, legislation, and funding) should satisfy everyone's appetite. Ken Kozole spent many hours reviewing films for the Multi-Media Theatre and was the chairperson for judging the challenging Easter Seal Student Design Competition.

Judy Harkins, along with her local committee brought us CAPITAL entertainment and folklore as well as the opportunity to rub elbows with politicians! All who have worked with Judy this year can appreciate her organizational skills.

The SIG chairpersons and their colleagues never cease to amaze me at the effort they put into providing new and interesting events for their members. This year there are more special SIG sessions than in any other year. This shows the determination of the members to bring as much new technology and sharing to the conference as possible.

With such a packed conference, it is often frustrating to find that most of us would like to be in two places at one time. At least we can't complain that we're bored!

It is with sincere gratitude that I thank Pat Horner, Susan Leone, and the rest of the RESNA professional staff for their hard work and diligence in bringing this conference to the professional status that it is today...

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CONCEPT TO CONCRETE: MARKETING ORIGINAL IDEAS IN AAC

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British Columbia Rehabilitation Society
(George Pearson Centre)

INTRODUCTION

During the 1980's and into the next decade, technology continues to dominate the quest to improve the quality of life for users of Augmentative and Alternative Communication (AAC). The range of options available to AAC users and clinicians is constantly expanding with advancements in technology. Sources of new ideas in the area of AAC technology are diverse and often surprising. Many innovations in this field arise from direct observation or experience with AAC, i.e.,users, families/friends of users, and clinicians. Innovators often become enthusiastic about an idea which may lead to improvements over existing technology. Despite this enthusiasm, many excellent ideas never reach fruition due to problems with technology, credibility, presentation, organization and funding. This paper will discuss the process involved in the development of an innovation in AAC technology: an Augmentative Telephone Booth (ATB), and the methods involved in gathering support (both moral and financial) for an idea which at first seemed impossible. We will attempt to reveal the methods taken to organize a disparate group of institutions, corporations and people to support and finance this unusual project. Finally, we offer a retrospective critique of our methods.

THE IDEA

The authors provide communication services in a unique long-term care facility serving severely disabled young adults (200 residents and 60 outpatients). The residents have primarily neurological disorders; approximately 33% of the residents are non-speaking and many use AAC devices. While AAC devices provide users with increased access to their immediate community, access to standard telecommunications has remained an obstacle.

The authors conceived of a computer-based telecommunication system for non-speaking people who are unable to use conventional telecommunication devices. The Augmentative Telephone Booth (ATB) consists of a microcomputer with a high quality speech synthesizer, specialized software, a modem-telephone interface and a number of adaptive peripherals. The booth is an architecturally designed, modular construction, well lighted and ventilated. The design incorporates: acoustic damping materials to ensure privacy; a side window for outside monitoring and security; an automatic door; and a telephone line. Users of the ATB hook into the system with a serial cable from their device or use adapted peripherals situated in the booth. Each user has their own file in the computer which they access through code words. Users have the advantage of being able to "speak" to and hear the people they are calling, an option not available to users of TDD's (the only alternative available to non-speaking people).

METHOD

Organizing Ideas into a Coherent Plan

The initial ideas were organized into a rough proposal that could be evaluated by other interested parties. This first proposal identified the need for the ATB and rudimentary aspects of the technology. Rough estimates of costs were included as a base line. The preliminary proposal was discussed with the Clinical Engineering Dept. of the local university to determine the feasibility of the ATB.

Tapping Local Resources

The university Clinical Engineering Dept. was willing to provide technical feedback on the cost, design and feasibility of the ATB. Concurrently, the facility administrator committed organizational support (i.e. cooperation, space, and staff time). A survey of local funding bodies determined the potential for financial support for the ATB.

Identifying Concerns of Potential Supporters

The facility wanted to move the current patient telephone out of the library area. They were receptive to new ideas regarding the telephone and were willing to make space elsewhere. The Women's Auxiliary attached to the facility was interested in funding a major project. The Employees' Fund of the local telephone company had just financed a major technical aids laboratory at a sister facility and was receptive to a project of this nature. The university was looking for projects for its engineering students and opportunities for future research.

Creating a Network

In the first month, all initial players wanted the reassurance that they would not be the sole supporters of the project. Support, or the intent of support had to be generated almost simultaneously from all initial players to form an interdependent web of encouragement. For example, the administrator needed the opinion of the university engineers concerning feasibility of the project and input from community funding bodies regarding their interest; the university wanted to be confident that the administrator had the resolve to proceed and would commit adequate space and staff time, and that community funding was likely, etc. The initial network consisted of: the authors, the facility, the university, and the Telephone Employees Fund. The creation of this network provided the security for the initial players to risk support for the ATB and provided a foundation to raise support from new players.

Selling the Idea

At this point a formal proposal was written and was to become the major promotional tool for more financial support. The proposal contained the following:

- Introduction
- Why develop an ATB?
- How will an ATB work?
- What are the social implications of an ATB?
- Why support the development of an ATB?
- Who is supporting the development of an ATB?

- Related research and development.
- ATB Budget

The proposal was reviewed, criticized and questioned throughout the initial network to arrive at an intelligible and motivating document. The network directed the authors towards organizations and corporations likely to support the ATB, eg: the facility administrator had connections with the Women's Auxiliary and a major computer manufacturer; the university had connections with a telephone equipment manufacturer; the Telephone Employees Fund directed the authors to the local Telephone Company and to a sister Employees Fund of a major airline. Each organization required an individual presentation with follow up letters and calls. The approach taken with each organization was tailored to its special interests in community affairs; information on the characteristics and interests of these organizations was provided through the initial network and contributed towards the "sale" of the idea.

DISCUSSION

At the outset of the project, a broad base of support was pursued with the assumption that funding and commitment would be difficult to obtain. The broad base approach had positive and negative consequences: it revealed a wide scope of potential interest and involvement in the project which helped to build enthusiasm and lent credibility; but, it dispersed energies among too many groups and did not allow time to cultivate special interest supporters. For example, the vice-president of the telephone company was sufficiently impressed to make a personal presentation on our behalf to the Telephone Pioneers. The Telephone Pioneers were enthusiastic about the idea and independently offered financial support. The Pioneers suggested that perhaps the ATB could be made a "purely telephone industry project." Our failure to recognize potential special interest groups resulted in wasted time and effort. More extensive research and a more detailed scrutiny of the project may have led us to a special interest group sooner and shortened the search for funding.

Several prime motivators for participation in the project emerged in the formal proposal: the originality of the idea; the altruistic and enabling nature of the project; the opportunities for research and continued development; the assurance of documentation and media exposure. Each group claimed a different subset of motivators as their basis for participation, but among all participants, the most prominent motivator was the notion of originality.

The establishment of a core network proved to be the catalyst for the development of the idea. Once the initial players were secure in the knowledge of common participation, they accepted responsibility for the welfare of the project. The network fed itself, and once set in motion expanded almost independently.

The ATB was an unconventional concept and encompassed some potentially negative aspects common to many original ideas: unproven, poorly understood, and relatively expensive. However, like many original ideas it was inspiring and intriguing; in retrospect we regret that we did not pursue the ATB when it was first envisioned in the previous year. At that time, the obstacles appeared too daunting. We needed a further year of thought and mutual persuasion to see the true potential of our idea. To conclude, the ATB project was an excellent exercise in the process of marketing an original idea in the field of AAC. Our recommendation to others who may be harbouring an original idea: brave the unknown! Originality sells itself.

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STIMULUS AND LISTENER FACTORS AFFECTING THE INTELLIGIBILITY OF SYNTHESIZED SPEECH

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ABSTRACT

As synthesized speech is increasingly used in augmentative communication aids and educational software, researchers have begun to map out the relationships between stimulus-related and listener-related factors and the intelligibility of synthesized speech. This information has value for developers in the design of new systems and for clinicians in the prescription of existing systems. This review summarizes the results of sample studies on such factors as length of utterance, meaningfulness, response sets, age, cognitive load, exposure, and language impairment. Implications for future research are suggested.

INTRODUCTION

The incorporation of synthesized speech into augmentative communication systems and educational software has increased significantly in recent years. Speech output can permit people who are blind or cognitively impaired to read. It can permit educational software to provide instructional prompts, encouragement, and feedback that improve students' attention, learning, and memory (8). It can permit a person who is severely speech-impaired to be a more equal and active partner in a communication dyad (1).

The methods of producing synthetic speech and the characteristics or quality of the resultant output vary quite widely. Despite the recognized benefits of speech synthesis applications, research-based information on the stimulus and listener factors that influence the intelligibility of synthesized speech is quite fragmentary. Because this information has important ramifications for developers in the design of new systems and for clinicians in the prescription of existing systems, the purpose of this review is to examine and summarize the current research literature on these factors and to suggest directions for future research in this area.

STIMULUS FACTORS

Researchers have employed a variety of stimulus conditions to test listeners' ability to understand the speech output of various systems. Thus far, the following stimulus sets have been investigated: (a) <u>single words vs sentences:</u> intelligibility is improved, particularly with low-quality synthesizers, when the length of the utterance is increased, irrespective of the linguistic significance of the utterance (2, 5,),(b)<u>meaningfulness</u> vs meaninglessness: intelligibility improves when the lexical units are used within a meaningful context allowing the listener to make use of linguistic knowledge (c) <u>open vs closed response sets</u> error rates for open response sets (those for which the listener writes or speaks the word just heard) are much greater than those for closed response sets (those for which the listener selects from a limited number of choices the word just heard. Open response sets can be useful as diagnostic tools in identifying poorly synthesized phonemes by providing unbiased estimates of the most common types of perceptual confusions possible with each phoneme (3).

LISTENER FACTORS

Research has identified several factors that might influence synthesized speech intelligibility. These conclusions should be regarded as tentative, however, because of the lack of replication and the methodological problems inherent in some of the studies, (a) <u>age of the listener</u>: adult listeners (age 26-40 years)understand a greater number of synthesized single words than children (age 6-12) do (9). (b) <u>cognitive load</u>: synthesized speech may be less intelligible than natural speech because it places greater demands on the cognitive resources required to process, maintain, and store information in memory (6). (c) exposure: synthesized speech becomes increasingly intelligible as the listener experiences some additional exposure to it, although the gains are not typically large (4, 5, 10). This exposure effect is attributable to listeners' ability to learn effective cognitive and perceptual strategies to improve performance. Exposure requirements are likely to vary with the quality of the synthetic speech. (d) language impairment: children with language impairments have greater difficulty understanding synthesized speech than natural speech and this reduction in performance is greater than that experienced by children with no language impairments (7).

IMPLICATIONS

Existing research on the intelligibility of synthesized speech has been limited primarily to comparisons of various commercial products. The most challenging, functional questions remain unanswered. Research that investigates the systematic variation of essential attributes of the speech waveform would significantly advance our understanding of the factors that contribute to intelligibility. Also valuable would be a more extensive exploration of the interaction of synthesized speech intelligibility with listener and environmental variables, such as intelligence, speech and language impairments, attention deficits, age, noise levels, and types of exposure.

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A Study of Reactions to Selected Augmentative Communication Systems

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The purpose of this study was to examine the reactions of viewer/listeners to individuals using selected augmentative and alternative communication(AAC) systems, i.e. a manual communication board and a microcomputer with synthesized speech. The data collected revealed that negative reactions are implied to persons using an (AAC) system. Important agreement of viewer/listeners with negative reactions was obtained in the categories of social behavior, vocation, technical characteristics, intelligence and general personality traits. Viewer/listeners implied some and rejected other negative characteristics to the person using AAC systems in this study. This study addressed two AAC systems out of a field of many, indicating a need for investigation of persons using other AAC systems.

Introduction

The purpose of this study was to examine the question "Do listeners imply negative characteristics to a person using an augmentative communication system?" Additionally, it was hoped that some light would be shed on some particular negative reactions that people experience when interacting with AAC systems users. The study was patterned after a listener reaction study concerning voice quality disorders(1).

Very few listener reaction studies have been done with persons using AAC systems and even fewer with AAC users cast as persons who interact in community settings. Research has been done concerning training and use of AAC systems for users and caregivers in institutions and other "sheltered" environments(2). The mechanics of conversation in these environments have been studied(3), i.e. systems, formats and procedures, whereas issues of conversational interactions between AAC users and people in the "mainstream of life" have received much less attention.

Methods

Stimulus material was developed in the form of a videotape depicting a person communicating scripted sentences with the aid of first a microcomputer(Apple IIe, 5¼" drive, monitor, standard keyboard, ECHO speech synthesizer and Keytalk(4) program) and then a manual communication board(table easel with felt board and Picture Communication Symbols(5) enlarged 259% attached). A person who could project the image of an actual AAC user was selected as the stimulus subject.

Opinion statements, negative verbiage related to social behavior, vocation, technical characteristics, intelligence and general personality traits, were developed by selecting categories of statements and then statements under each selected category and assembled as a continuum of 39 opinion statements. Listeners watched the videotape and marked the response booklet containing the opinion statements with an A for agree or a D for disagree next to each statement. Listeners also filled out a Biographical Data Form, which was developed as part of the response form.

Listeners were selected to represent a collection of people found in the community. An additional consideration was that this collection of people not be a group of people who were involved generally with augmentative and alternative communication.

Results

The viewer/listeners' responses indicated that some negative reactions were implied to persons using an AAC system while other negative reactions were rejected. The most important agreement with implied negative characteristics were related to feelings of discomfort, perceived normality, communicative clarity and frustration. Rejected characteristics included capability to interact socially; emotional scenes; labeling as "pessimist", "strange" and "not outgoing"; expectation, competence, reliability and alertness to work; unintelligent appearance, slowness.

Biographical data revealed that the average viewer/listener in the study was 42 years old, male or female, had a bachelors degree and was a professional.

Discussion

The statement "most people would feel uncomfortable when associating with this person" drew 89% agreement and suggests that discomfort when engaging in conversation with a person using an AAC system is not an isolated reaction. In a similar study, Knight(1) found listeners agreed significantly when presented with audio samples of severe voice quality disorders. People are not likely to view atypical persons and their AAC systems as being part of the mainstream unless they interact with them frequently in the mainstream of life, i.e. grocery stores, shopping malls, restaurants, parks, theatres, etc. Listeners(71%) indicated a realization that persons using AAC systems do have a contribution to make to society. Most respondents disagreed with the idea that "This person should not be expected to work." Statements concerning perceived intelligence were rejected, e.g. "This person does not look like someone who is intelligent". Listeners appreciated the possible frustrations with sending messages in augmented ways. The difficulty with understanding the message is affected by a number of factors, not the least of which is society's pressure to converse and move on without losing a great deal of time in the effort. None of the statements concerning general personality traits was given important agreement.

One limitation of this study lies in the fact that there are many different types of AAC systems, communication symbol sets and formats for presenting those sets that were not investigated. It can be concluded that the listeners in this study did imply negative characteristics to the person using augmentative communication in this study. Listeners also rejected some negative characteristics that were suggested for implication to the person using augmentative communication. More studies are needed to confirm that negative characteristics are implied. The general public needs to be more aware of persons using augmentative communication and how to interact with them. Further research needs to be conducted concerning what the public needs to know as to how to interact with people who use AAC systems.

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MAXIMISING INDEPENDENCE IN THE INTENSIVE CARE UNIT - A CASE STUDY.

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ABSTRACT

W was admitted to the Intensive Care Unit (ICU) following a head injury. This paper describes the clinical engineering unit's involvement with W over the following four months as his condition improved from total paralysis below the neck to sufficient independence to allow his return to mainstream schooling. The key professional role of the Clinical Engineer is highlighted in W's assessments and computer based activities. These activities are designed to encourage independence in an environment which normally dictates total dependence.

REQUEST

The Clinical Engineer received a request from the Consultant in Disability Medicine, 19 days after admission, to provide W with access to a communication system and leisure activities. Speech therapists from the Communication Aids Resource Centre and specialist staff from the Young Disabled Unit (YDU) were also involved.

INITIAL ASSESSMENT

The initial assessment of W revealed a 14 year old boy, paralysed from the neck down and ventilated through a tracheostomy tube. The differential diagnosis was pneumococcal meningitis and brain stem infarct. No significant recovery was expected.

Although W had no speech, he was not totally without communication. W closed his eyes for 'yes', trembled his head for 'no' and mouthed words without voice. His comprehension and literacy skills were normal. W's only voluntary movements were of the head, mouth and eyes. He was able to flick his eyes from left to right upon request, but found head movements difficult.

As W's condition was not expected to improve, emphasis was placed on improving communication and providing leisure activities to maximise his feelings of control over his immediate environment. There was concern that W should not become passive or 'locked in'.

EQUIPMENT ACCESS

The interface assessment was carried out by the Clinical Engineer who was soon able to discount the use of head and mouth movements for interface control. The former proved tiring and any interface placed near his head would need resiting as his position was changed. Extra tasks for ICU staff were avoided where possible. W already used his mouth for forming words and it was felt inappropriate to add another function to this site.

The eye movement switch, Twinkle (1), was trialled and after a 15 minute training session with the Clinical Engineer and Clinical Engineering staff nurse, W was using the switches well to play a simple computer game. The eye switch consists of a neonatal cardiac electrode placed on each temple, which detects the changes in orientation in the corneo-retinal potential as the eyes move. The electrodes are connected to a small unit housing amplification and filtering circuitry to provide a two switch output through an opto-isolation barrier for control of external devices.

Before the equipment was used in ICU, rigorous electrical safety tests were made. The computer was a mains powered BBC B and did not meet safety standards laid down in IEC601/1 for patient connected equipment. The Twinkle eye switch was designed to provide effective electrical isolation for the patient through its opto-isolation barrier and after the whole system had been subjected to earth leakage current tests, it was agreed that so long as the computer, monitor, disc drive and printer were placed at the foot of the bed outside the immediate patient environment, the whole system could be used.

COMMUNICATION

W needed to discuss his present circumstances with family and staff. Yes/no answers reinforce passivity and require the conversation partner to be a mind reader in counselling sessions. W's silent mouthings were often ambiguous and led to further frustration as misunderstandings were compounded.

In line with Dowden's approach (2), an artificial larynx was considered. However, an appropriate model was not available immediately. To provide the immediate means for novel, unambiguous communication, W was introduced to scanning wordprocessor software, Beeblinc (3) on the BBC B computer.

Through daily, timetabled training sessions with the Clinical Engineering staff nurse, W quickly progressed from writing his name on the screen, with letters chosen from a 3x3 matrix, to writing key words selected from the full letterboard while his family was visiting. W also used the system early in the day before tiring, to print out messages for his visitors and letters to friends.

LEISURE ACTIVITIES

W used the Twinkle eye switch to control games software and became proficient at switch versions of various competitive games in which he soon involved ICU staff.

This introduced these staff to the system which developed their confidence and led them to fitting the eye switches themselves and setting up the computer. Simple fault finding and support was carried out by the Clinical Engineering staff nurse.

W enjoyed the computer games and companionship they brought and was soon requesting more complex games. Work was already underway on emulation techniques and W was introduced to the software version of 'Monopoly'. Using a keyboard emulation interface (KEI) and purpose written software an a Husky Hawk hand held computer, W played the game using a switch. His opponents used the keyboard to make their selections whilst W. scanned through responses expected by the game displayed on the Hawk. He was able to play the game at normal speed and therefore found plenty of willing opponents.

IMPROVEMENTS

After a further two weeks W began to regain control of the left side of his body. He was soon able to use a lever switch with his left hand and transferred to this from the eye switch. An infra-red switch transmitter/receiver was incorporated to maintain electrical isolation.

W trialled a hand held Cooper-Rand artificial larynx but found it unacceptable, primarily because of the robotic nature of the voice, and also due to the involvement of the conversation partner.

As W's condition continued to improve, he was gradually weaned off his respirator and spent time sitting out of bed. He was transferred to a Medical Ward eight weeks after his admission to ICU, and had his trachoestomy tube removed, whereupon W's speech returned. He was transferred to the YDU for intensive therapy.

In discussion of W's further rehabilitation programme, the Clinical Engineer was approached to specify a system for producing written work at school. Through the Augmentative Communication Evaluation System software package (Words+ Inc., California), W's left hand and arm function was shown to have improved to the extent that single handed typing speeds were within the normal range but slower for the right side. A portable computer and software was recommended with information on computer based curricular activities coming from the Education Authority's specialist unit.

After five months, W returned to school on a part time basis while still resident at the YDU. Three months later he was discharged home, attending the YDU only as a day patient and in a short while commenced full time education again.

DISCUSSION

W was provided with appropriate assessment, equipment, training and opportunities for use of augmentative communication and leisure equipment in the ICU. This aided W's interactions with family and staff at a difficult time. Communication breakdown was avoided as W used the scanning word processor to write key words.

Siblings and friends were able to play with W through the computer games, thus maintaining contact in a distressing environment. W enjoyed the competitive nature of the games and took great delight in beating opponents. The value of rehabilitation for W in the acute stage was amply demonstrated.

Safety considerations relating to equipment provision in ICU were of prime importance. Electrical isolation for the patient was maintained at all times, with mains powered equipment kept outside the immediate patient environment.

CONCLUSION

Our success in maximising W's independence in ICU was achieved through a combination of Clinical Engineering staff skills in assessment, planning, system specification and provision, training, liaison and commitment. The ability to build appropriate systems from existing hardware modules and configurable software meant we could meet the demands of a rapidly changing situation.

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QUANTITATIVE MODELING IN AUGMENTATIVE COMMUNICATION -- A CASE STUDY

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INTRODUCTION

A general model that accounts for all the component cognitive, perceptual, and motor processes in a user's interaction with an augmentative communication system can be a powerful clinical tool. A model can provide an improved understanding of the user's performance, as well as predict the effect of changes to the system.

This paper presents one example of quantitative modeling in clinical AAC practice. A simple model for single switch letter scanning is presented. Clinical application of this model is illustrated through a case study. The patient's progress is demonstrated through actual communication rates, and these measured rates are compared to those predicted by the model.

A QUANTITATIVE MODEL

The modeling technique used can be thought of as a quantitative task analysis, in which the overall task is divided into individual steps. Time required to perform the overall task can be estimated by summing the times for each component step. The following example illustrates the technique for modeling error-free performance.

The task considered is to generate text by selecting individual characters (including "space") from a row-column scanning array. The character positions are fixed and are arranged alphabetically as shown in Fig. 1. Scanning proceeds automatically at a definable rate. The user selects the desired character by first hitting a switch when its row is scanned, then hitting the switch again when the character itself is scanned.

A	B	C	D	E	F	
G	H	I	J	K	L	
M	N	O	P	Q	R	S
T	U	V	W	X	Y	Z
space						

Fig. 1. Alphabetic array for System A.

The steps required to select each character are as follows: scanning to a character's row and column and two switch hits for character selection. The total scanning time to reach a character depends on its position in the array and the system scan rate, s (1). Scanning time for an individual character, i, can be expressed as $(d_i)(s)$, where d is the distance in scan steps from the upper left hand corner. Note that $d = 0$ for the character in the upper left hand corner. The average scanning time for overall text generation is the weighted average of each character's scanning time, based on each character's relative frequency in English (1, 2). For an alphabetically arranged character array, the average scanning time can be calculated as 3.98s, where s is the scan rate.

The time required to activate the switch two times can be represented as 2h, where h is the user's switch hit time. The average overall time required to select a character from the alphabetically arranged array, then, is the sum of the average scanning time to reach the character and the switch hit time, or $T = 3.98s + 2h$, in seconds/character.

The scan rate must be set to allow time to search for the desired character, perceive when it is scanned, and hit the switch. Therefore, the switch hit time, h, must be less than the scan rate. A simplifying assumption that $h = s/2$ is made throughout this paper, because the scan rate incorporates switch hit time as well as the processes listed above.

CASE STUDY

Patient A.B. is a 64 year old woman, who is ventilator-dependent and unable to speak, secondary to Fisher variant of Guillain Barre Syndrome. Due to extensive axonal damage to the bulbar nerves, her recovery of independent speech is expected to be long term. Augmentative communication intervention was initiated in the Intensive Care Unit. A letter board was initially implemented, but it was cumbersome and resulted in limited responses. Two weeks after onset, A.B. was able to consistently protrude her mandible to operate a computer-based single switch scanning system.

There were two main criteria for the system: (1) large character display, to accomodate vision problems, and (2) simplicity, given the acute illness and difficult environment. The system chosen, referred to as System A, runs on an Apple IIc computer and employs group-item scanning. On the top level menu, it presents alphabetically arranged letter groups (A to F, G to L, etc.). When the user selects one of the groups, the screen is updated to display only the characters of the selected group. This technique is equivalent to the row-column scanning approach described above.

Over two weeks of daily practice, A.B. gradually improved to become an expert user, exhibiting very few errors. While A.B. had reached the optimum performance for her system, she did not use the system regularly because she found the text entry rate too slow. Data collection was initiated at this time, which revealed that her text entry rate was only 3.1 characters/min. It was observed that two limitations of System A contributed to the slow measured rate: (1) for each character selection, 10 seconds was required to update the display, and (2) the fastest scan rate was 1.6 sec/scan.

A modified version of the model described above was used to predict optimum rate. The 10 second display update time must be added to the basic equation derived above, so $T = 3.98s + 2h + 10$ sec/character. With a scan rate of $s = 1.6$ sec/scan, the predicted rate is 3.33 character/min. This matches the measured rate closely and yields support for the modeling approach.

Since A.B.'s scanning skills had significantly improved by this time, a more complex scanning system was introduced in response to her request for a faster system. In this system, referred to as System B, characters are arranged in a frequency-based array, so the more frequently used characters are closer to the upper left hand corner of the array. All characters are displayed simultaneously as large graphics characters in a fixed row-column arrangement, so lengthy screen updates are not necessary.

System B was modeled before A.B.'s initial trial, to predict how her performance might improve with the new system. Since the character arrangement is more efficient than System A, the average scanning time is decreased to 2.59s, where s is the scan rate. Switch hit time for each character remains 2h, where h is the time it takes for a single switch hit. There is no measurable screen update delay, which immediately saves 10 seconds per character. There are, however, two clinician-programmable delays in the system that must be incorporated into the model. The first is a pause, p, after a character is selected; this gives the user extra time to search for the next character before row scanning begins. The second is a row delay, r, after a row is selected; this gives the user extra time to select the first item in the selected row, since some users have difficulty hitting a switch quickly twice in a row. The average time per character, then, is $T = 2.59s + 2h + p + r$.

Using A.B.'s previous scan rate of 1.6 sec/scan, and assuming $h = s/2$, text generation rate for the new system was expected to be 10.4 characters/min, or three times her rate on the previous system, with no selection or row delays ($p = r = 0$). Therefore, immediate improvements in text generation rate were expected. Additionally, because System B places no limitation on the scan rate, further improvements with practice were expected.

In A.B.'s first two trials with System B, she achieved text entry rates between 6.1 and 7.8 characters/min, essentially double her previous rate. These actual rates are lower than the predicted optimal rate because selection and row delays were required to compensate for A.B's unfamiliarity with the arrangement of the character array.

Over the course of one month from the introduction of System B, the system parameters (scan rate and delays) were adjusted in response to the improvement in A.B.'s skill, resulting in a top text entry rate of 19.6 characters/min. Error-free text entry rates for each set of parameters were measured and compared to the model's prediction. These results are tabulated in Fig. 2, showing the measured rates matched the predicted rates quite closely.

Parameters (sec) s	p	r	Meas. rate (cpm)	Pred. rate (cpm)
1.44	1.0	0.0	9.7	9.7
0.96	1.36	0.36	13.9	11.6
0.6	0.6	0.1	19.6	21.0

Fig. 2. Measured vs. predicted rates for System B

DISCUSSION

The model can also be used to predict the maximum possible rate for System B. The minimum switch hit time, h, can be modeled as a simple reaction time, taking 0.2 seconds for an individual with normal cognition and motor skills (2). The minimum scan rate, s, can be set at the time it takes to perceive a character on the display and match it to an image of the desired character, plus the switch hit time. This assumes that the character positions have been memorized, so no search time is required. For an individual with normal cognition and perception, the minimum s is 0.4 sec (2). With no additional delays, the optimal rate is predicted to be 41.8 characters/minute. It should be noted that this assumes peak performance at all times, and it is not realistic to expect an individual to maintain this level of performance for long periods of time. However, it does provide an absolute maximum rate that can be used to gauge absolute progress.

Continued work with A.B. will focus on further improvement in text entry rate. Techniques such as abbreviation expansion or word prediction may be introduced in an attempt to improve text entry rate. Rate measurements will be taken to determine the effectiveness of these techniques. This will require word prediction packages that display large characters, which are currently not commercially available. In addition, a similar modeling simulation has indicated that single switch Morse code at an expert level could be faster than single switch scanning. The option of using Morse code has been discussed with A.B., but she has indicated that she is not interested in learning a brand new technique at this point.

CONCLUSIONS

Our results indicate that a simple model can be a useful predictor of communication rate. The model can be used to formulate strategies to improve performance because it reveals how each component step contributes to overall performance. Continued work to further validate the model is necessary. Finally, taking quantitative measurements of performance is by itself important because it gives an objective measure of a user's progress. Manufacturers of computer access or augmentative communication systems are urged to consider including data collection modules in their systems, to assist clinicians in this type of quantitative assessment.

ACKNOWLEDGEMENT

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MOUNTING A PC-BASED COMMUNICATION AID: A CASE STUDY

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ABSTRACT

A mounting system that allows the use of a computer-based communication system from a wheelchair without compromising mobility or other function is described. The communication system consists of a portable PC, with the screen separated from the computer, and a speech synthesizer. This system was developed to meet the specific needs of an individual, but the concepts are useful for others with similar equipment and needs.

BACKGROUND

M.R. is a 28-year-old woman who is severely speech-impaired due to a head injury in 1977. Since October 1987, she has been speaking and writing with a Zenith Supersport[a] laptop computer and a portable DECtalk[b] speech synthesizer (1). She accesses the computer with single-switch scanning using Altkey, a keyboard emulation package (2).

Initially the system could be carried and set up when she wanted to use it, but was not truly portable. M.R. wanted to be able to use the system independently from her wheelchair whenever she needed it. The first approach to this problem was to use the computer on her lapboard with a mounting for the DECtalk on the back of the wheelchair. However, with the computer on her lapboard, M.R. had difficulty seeing the screen, and raising the computer so she could see the screen obstructed her view and hid her from others. Additionally, since the lapboard was often in her way and took a long time to set up, she did not always want to use it. To alleviate these problems, an alternative mounting system for the computer was required.

DESIGN

Based on an evaluation of M.R.'s needs, a set of criteria were developed. The goals for the mounting system were that it:

- be easy to set up and move between her manual and power wheelchairs
- allow the screen to be positioned near eye level without obstructing vision
- not interfere with driving, transfers, or other functions
- provide adequate protection for the computer and DECtalk.

A commercial swing-away computer mount such as the Quick 'n Easy[c] was initially considered. This would be easy to set up and make the height of the computer adjustable, but it would still block her view. Also, when moved to the side position, it would have added to the width of the chair and exposed the computer to possible collision damage. It became apparent that the best way to meet M.R.'s requirements would be to mount only the computer screen in front of her and to mount the computer base and DECtalk behind the chair. This type of approach was feasible since M.R. uses scanning and does not need access to the computer keyboard.

The screen was separated with the assistance of local Zenith service technicians. The ribbon cable connecting the screen and computer was cut and a standard DB25 connector placed on each end. A standard RS232 extension cable was used to connect the computer and screen.

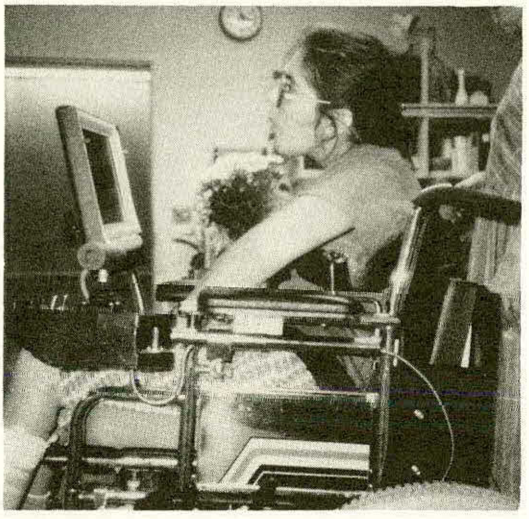
A thermoplastic shell was made to help protect the screen. Strips of foam were placed between the screen and shell to help protect the screen from impact. The shell also makes the screen more resistant to twisting; this was important since the screen was no longer protected by being connected to the computer. The screen was attached to the shell using strips of Polylock[d].

The shell was attached to a bracket using T-nuts so the mounting surface for the screen would be flat. The bracket holds the screen and shell to a Prentke Romich Wheelchair Mounting Kit[e]. This allows the screen to be rotated flat, providing increased vision when driving. By installing a bracket for the Mounting Kit on each wheelchair, the screen and bar can be easily moved from chair to chair.

A cover was made to protect the keyboard, since it was no longer shielded by the screen. Thermoplastic was bent to fit and attached to the sides of the computer with Velcro[f].

A mounting for the computer and DECtalk was made for each chair out of .125" thick aluminum painted to match the wheelchairs. The pieces were cut to size, bent, and bolted together to form a rectangular box to hold the computer. The boxes were attached to the chairs using the existing upholstery screws. On the power chair, the computer rests on top of the wheelchair controller. A bottom bracket was added to the manual chair to support the computer. Enough of the back of the computer was left exposed to allow clearance for the cables. A slot was cut in one side of the boxes to allow access to the power switch without moving the computer.

Four key-hole slots were cut in the back plate of each mounting box to hold the DECtalk. The bottom of the DECtalk was fastened to an additional aluminum plate using Polylock. Rubber feet screwed to the plate fit into the key-holes to attach the plate to the computer mount. When it is not being used on the chairs, the DECtalk can stand on these feet. A strap with a quick-release buckle wraps around the DECtalk and back plate to prevent rattling and provide a backup to the Polylock.



M.R. with her communication system. The DECtalk is not shown but mounts behind the computer.

DISCUSSION

In this case, removal of the computer screen and development of a separate mounting system for the computer and DECtalk proved to be a successful solution to a specific problem. M.R. reports a high degree of satisfaction with the system; its portability allows her to communicate in a wider variety of situations. However, there are a number of issues that need to be considered before attempting to separate a screen from a computer. Laptops are not designed with this in mind, so even knowing that it has been done with other laptops, there is no way of ensuring it will be successful with a specific computer. Attempting to separate the screen voids the warranty for the entire computer, and once removed, the screen will be more exposed and vulnerable to damage. The longer connecting cable may introduce undesirable noise to the video signal, and disconnecting the cable while the computer is on may damage electronic components. These risks should be discussed with the client and balanced with the potentially considerable benefits before any work is started.

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b. Institute on Technology, 300 Longwood Ave., Fegan 9, Boston, MA 02115.

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d. Consumer Care Products Inc., Sheboygan, WI 53081.

e. Prentke Romich Co., 1022 Heyl Road, Wooster, OH 44691.

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A PORTABLE DRIVER MEASUREMENT SYSTEM

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ABSTRACT

The authors have developed a device to assist them in determining the physical parameters of potential drivers in order to compare them with the available adaptive driving equipment and with the configuration of various vehicles. The prototype described here was designed to fit the following criteria: 1) measures position\, operational range, size, and force capability of a subject using simulated steering, hand brake and throttle controls while allowing the use of interchangeable control grip interfaces; 2) allows and assists with the measurement of all relevant body parts, range of motion and personal equipment (i.e. wheelchair) components in three dimensional space in the driving position; 3) is portable, with no single component weighing more than 30 lbs and the total weight not more than 65 lbs; and 4) is easy to assemble, adjust and use without special training.

PURPOSE

The system was developed to precisely measure the functional upper extremity strength, range of motion and anthropometry of a potential driver seated in a wheelchair or a simulated driver's seat. It is often difficult and costly to transport persons with severe disabilities to a suitably equipped driver evaluation center. This portable device can be carried in a passenger car and set up in any location convenient to the subject. The measurements thus obtained are used to select and/or recommend specific modifications and adaptive driving equipment for the potential driver. A similar but less versatile device has been in use for about seven years and has proved to be a valuable screening and prediction tool.

The two major components of the system are the SIMULATOR and the CAMERA. The simulator provides the structural reference framework for taking anthropometric measurements. It also contains the force adjustment and measurement mechanisms for steering and hand brake-throttle actions.

THE SIMULATORS

Steering

The steering component is adjustable for wheel diameter, grip device, spatial orientation, and force resistance. The wheel contains an adjustable slide with a bearing receptacle into which various spinner handles can be inserted. The slide passively locks in 1/2" indices to provide a range of steering diameters in 1" increments from 7" to 14". The steering plane may be varied by rotating it around two axes: 1) Horizontal, parallel to the subject's transverse plane and 2) Horizontal, parallel to the mid-saggital plane. Steering resistance is controlled by a magnetic particle brake. A ten turn switch enables the operator to vary the steering resistance from 0 to 2000 inch-ounces. The torque is displayed digitally as the wheel is turned.

The height of the steering plane is adjusted by rotating the shoulder box around the cross tube which supports it (Appendix A). Figures 1, 2 and 3 show the ranges of steering wheel positions with the declination of the steering wheel in three representative angles; vertical, 45 degrees, and horizontal respectively.Maximum knee clearance is 30 inches with the device assembled in the normal manner, however it is possible to gain considerably more by reversing the mounting of the shoulder box.

Hand brake-throttle

The hand brake-throttle is permanently mounted in the neck box approximately 7 3/4 inches below the steering wheel, with handles for both right and left hand operation. The handles are drilled to accept various spinner type grips as on the steering wheel. Motion of the handle (either right or left) is bi-directional along any of three axes, 1) Vertical (up,down), 2) Horizontal, parallel to the mid-sagittal plane (forward,back), and 3) horizontal, parallel to the transverse plane (left,right). Thus the motion of mechanical or power assisted brake-throttle controls can be simulated with reasonable accuracy. The resistance of the hand control is varied by the use of three hydraulic cylinders each of which is adjusted by a pair of flow control knobs. Each pair controls the force required to move the rod back and forth in one axis of motion, giving a resistance range from 20 to 300 ounces. The forces are read directly on LCD panel meters.

THE CAMERA

The Polaroid SE600 camera is equipped with a 75mm lens and a 1 cm grid in front of the film plane. The imprint of the grid in the resulting photograph assists the operator in determining many of the significant anthropometric measurements of the subject and driving elements after they have been adjusted for optimum effectiveness in driving. It is, of course, necessary to standardize the camera position with respect to the DMS to achieve consistent measurements. Also, the grid can be used only to take measurements in a plane parallel to the film plane. Some of the useful measurements thus obtainable are overall or head height, eye level, reach envelope, wheelchair configuration, angle and position of steering wheel, etc.

DISCUSSION

The simulator is useful in its present form for any practitioner familiar with adaptive driving prescription. The adaptive equipment and structural modifications required for the individual driver can be more accurately prescribed prior to initiating costly modifications. Future plans include developing a protocol which will make it operable by para-professionals who may then turn the data over to specialists for interpretation. Useful additions will include scales and indicator marks on the DMS to further simplify the recording of measurement data. For example a protractor will be imprinted to show the angularity of the steering shoulder box. The steering wheel angle might be indicated by an inclinometer. These and other changes are being evaluated for inclusion in the next level of development.

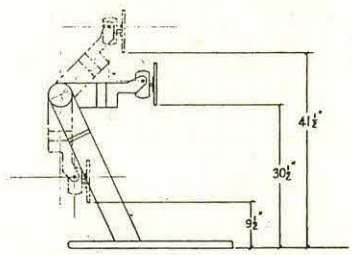

Fig.1

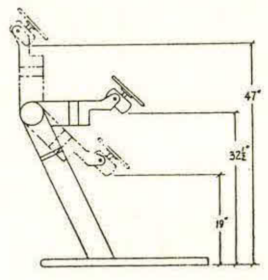

Fig.2

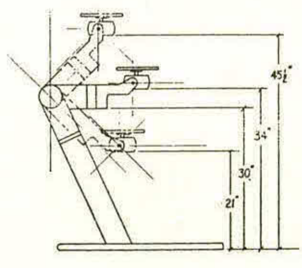

Fig.3

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APPROPRIATE DEVELOPMENT OF VEHICLE MODIFICATION PROTOCOL FOR MAXIMIZING TRAFFIC SAFETY OF DISABLED DRIVERS

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ABSTRACT

Many of the individual U.S. States and Canadian Provinces have some means of identifying and prescribing adaptive driving devices. The past several years have seen a progressive refinement of early vehicle modification guidelines and standards developed by the states of Massachusetts and California. In many instances clinical rehabilitation engineering has been called upon to assist in the development and implementation of systematic procedures for procuring appropriate adaptations for the disabled driver.

The independent operation of a motor vehicle is potentially one of the most hazardous consults that the rehabilitation engineer is faced with. Inappropriate identification and prescription of specific driving devices can jeopardize the safety of the user and the motoring public, and in many cases is avoidable.

A system of describing appropriate generic equipment has been developed by the Department of Human Services of the State of Indiana and is based on sound clinical practices used in several rehabilitation programs around the State.

INTRODUCTION

Many states have relied on independent vehicle modification vendors, and equipment manufacturers for recommendation of adaptive driving devices for the clients they serve. The Office of Vocational Rehabilitation is a major purchaser of adaptive equipment for the disabled and must obtain at least two bids on major purchases such as vehicle conversions. Most of these sources are unable to access the medical appropriateness of specific conversion options, or if the client is cognitively able to process the complex tasks that driving demands.

The consistent application of vendor prepared quotes have led to two unfortunate consequences. First the quote may be prepared in a way which excludes competitive bidding due interpretation factors. (One vendor may sense that the client can only drive a specific brand of vacuum gas brake interface which a competing vendor does not deal in). Secondly, vendor prepared bids often lead to the inability of the client to safely drive the intended vehicle. This is often the result of inadequate evaluation and education pre-requisites. The client with a severe disability is most affected because of the large outlay of money required by both himself and the funding agency. It is not uncommon for a high level quadriplegic to purchase a new van for $12,000-15,000 and the funding agency purchasing equipment in excess of $15,000.00 resulting in a delivered vehicle that is uncontrollable by the intended user.

The State of Indiana has recently developed Standards for Automotive Adaptive Equipment and Vehicle Modifications and refined their support service policies to guard against either of these conditions occurring. Michina Rehabilitation Institute has assisted in the development of these standards and policies and remains a model protocol for leveling the playing field in vehicle modification and traffic safety.

METHODS

Prior to the identification and prescription of an adaptive driving system the newly injured driver or the first time driver should complete an established driver evaluation. The evaluation should be followed by driver rehabilitation education/rehabilitation. Following the successful completion of the one or both of these programs rehabilitation engineer would be prepared to focus on appropriate vehicle modifications. General definitions of these programs follow:

DRIVER EVALUATION: The driver's evaluation is structured to respond to four separate concerns.

I-<u>Client Potential</u>: This assessment consists of two separate but closely related parts. The first portion is a objective static testing battery that would assess neurological and physical ability to operate a motor vehicle. The second portion is a subjective assessment of the clients ability to drive a similar vehicle through a prescribed course at various speeds ranging from 5 to 35 miles per hour.

II-<u>Treatment Required</u>: The clients need for driver education. If the focused assessment reveals that the client is operating the modified vehicle within established safety levels further driver education is not indicated. However, most cases reveal that the new driver requires multiple hours of traffic exposure to develop basic competency in the control interfaces and traffic safety procedure.

III- <u>Need for VMC</u>: The clients need for vehicle modification consultation. The clinical assessment can usually isolate issues such as transfer potential, appropriate conservative control interface and wheelchair mobility enhancements.

IV- <u>OEM CONSULT:</u> What original equipment manufacturer options should be selected to minimize the amount of after market conversion. In many cases aftermarket power windows are applied to new vehicles that should have had them from the factory.

DRIVER REHABILITATION/EDUCATION: This essential aspect of treatment assures that the patient who is unable to effectively operate a modified motor vehicle in the brief diagnostic evaluation can develop competency through a goal oriented treatment approach. Driver rehabilitation can range from as little as one hour for the previously licensed paraplegic driver to in excess of 50 hours for the severely disabled C.P. driver.

VEHICLE MODIFICATION CONSULTATION: The development of a bid ready, generically described consultation on necessary equipment is an area that the rehabilitation engineer has contributed most. A basic knowledge of existing Federal Motor Vehicle Safety Standards (FMVSS) and Society of Automotive Engineer (SAE) recommended practices helps in leveling the playing field. The diagnostic accuracy of medical evaluation and the demonstrated competency in the evaluation and rehabilitation phases of the driving program assure that the generic prescription is appropriate for the clients use. If properly applied a three part driver rehabilitation program can maximize traffic safety and eliminate the delivery of a conversion that the patient cannot drive.

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TECHNOLOGY TRANSFER: A CONSUMER-ORIENTED, INTEGRATED MODEL

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Introduction

In carrying out our technology transfer program we have determined a need for a model that follows the principles of new product development that are used in successful private sector firms, but have not often been applied to rehabilitation products. We have recently developed such a consumer-oriented, integrated model of technology transfer. It is designed to meet the expressed needs of disabled consumers and to provide manufacturers and distributors with the marketing and demographic data they need to make decisions on product viability.

This paper describes the consumer-focused, integrated model of technology transfer and our experience with it during the first nine months of its development and implementation.

Methods and Results

The model has six steps:

Step 1. Consumer Idea Generation: We convened four Idea Generation Groups (IGGs) totalling 13 adults with mobility impairments. For the initial IGGs we did not attempt to assemble a statistically valid sample of all disabled people, but aimed instead for variety. Groups included men and women, and were racially and ethnically diverse. Some participants had been disabled from birth or when quite young, others were disabled as adults. Diagnoses of participants included SCI, post-polio, cerebral palsy and MS. Some were employed, others were homemakers, others were unemployed. Living situations varied - some people were married, others lived alone or were single parents.

The task of the IGGs was to brainstorm on barriers to activities in their daily lives that could be lessened by the use of some device, and, when possible, make suggestions about the desirable features of the device. The groups spent two to three hours in discussion. A small stipend was offered to the participants.

IGGs generated just under 100 ideas for products to fill gaps in the areas of travel, personal care/grooming, recreation/entertainment/shopping, household/child care, wheelchair-related, and miscellaneous. Their ideas fell into several categories:

*Products that don't exist: e.g. *a "lazy susan" that revolves vertically instead of horizontally to allow access to items in the tops of cabinets.*

* Products that exist, but don't do the job well enough: e.g. *a buttonholer that works on the first try.*

* Products that exist, but are too expensive as currently designed: e.g. *a wheelchair seat raiser.*

* Products that need to be redesigned for travel: e.g. *a portable, lightweight bath stool.*

* Add-on products that make other items more useful to a person with a disability: e.g. *adapter kit for a 4-door auto allowing the driver's side rear door to open out from the center, to make stowing the wheelchair easier.*

* Products that would be useful, but that we'll probably never see: e.g. *a wheelchair-mounted cement cutter to make curb cuts as you go.*

Disabled consumers were later convened as Focus Groups to develop a list of specific attributes they desired in a product and to gauge their intention to buy the product.

Step 2. Product Design: The list of product ideas was screened to yield a dozen which were presented to Senior Design Students in the Department of Mechanical and Industrial Engineering at a major university. For their Senior Design Project, teams of students had the option of choosing one of these product ideas or one from a long list of more traditional products unrelated to disability. Their sole task during the final semester in the Engineering Program was to develop a working model of the chosen device. The university has an active rehabilitation program and engineering students were encouraged to consult with their disabled peers during the design and development work.

This was the first time that the list from which students could choose included rehabilitation devices, something to which very few had prior exposure. During the first semester, three teams selected items from this list. The prototypes they developed were a portable "universal" door opening aid which would help people with diminished use of their hands to operate door knobs and handles with greater ease, a hand powered bicycle that is more stable and easier to learn to ride than existing ones, and a patient bed lift designed to minimize back strain for the health professional transferring the disabled person. We are currently evaluating the prototypes that the students developed.

Step 3. Market Research: Through the U. S. Small Business Administration's Small Business Institute Program, graduate and undergraduate marketing students from three universities conducted market research on several devices. The students met with the project director to get an orientation to the field of rehabilitation and assistive devices. Information on disability awareness and appropriate terminology was also given.

In addition to tapping usual market research data sources, students contacted organizations in the area that provide services and do advocacy for people with disabilities. Despite the paucity of statistics on disabled people, students yielded credible research results. In some cases, their findings were that the size of the market compared to production costs for the product as designed meant that it did not have commercial potential. In another case, findings were that the individual and institutional market was sufficient to result in a reasonable return on investment. Research on additional products is underway as this abstract is being written.

Step 4. Distribution: Although in reality, distribution follows manufacture of goods, we approached distributors first to get feedback on this model and elicit their interest in adding a new item to their product line. We explained that we would only be presenting them with products for which the economic analysis revealed the likelihood of a reasonable profit. Not surprisingly, distributors with whom we met all expressed eagerness for products with a demonstrated profit potential.

Step 5. Manufacture: We are in contact with two types of manufacturers about their interest in the products under investigation. Traditional manufacturers of assistive living devices have been informed of the possibility that we might be able to present them with a viable new product to add to their line. We recognized, however, that many products may have a modest market with only a slim margin of profitability. Therefore, we also explored alternative manufacturers such as the prison-based Illinois Correctional Industries and the community-based Chicago Commons Industrial Training Program. These groups provide contract manufacturing using on-the-job trainees (OJT). Production costs are thus reduced which may transform the economics sufficiently to make an item profitable. Manufacturers are similar to distributors in that they are interested in having the opportunity to add a new item to their production line if there is documentation that their sales will be sufficient.

Step 6. Consumer Purchase: Disabled consumers purchase and benefit from the products they asked for. This assumes that appropriate channels of distribution can be found so that all consumers who desire the device have information about it and how to purchase it.

Discussion

For the sake of brevity, issues of third party payment, product liability and patents have not been discussed.

It is too early in the life cycle of this model to be certain of its success in bringing new products to market. However, we have made several findings of note:

1. Disabled consumers in the IGGs are active in the field of disability rights and services. All of them remarked, however, that they had never heard of an effort to find out what disabled consumers want by going directly to the consumers.

2. IGG group members would be considered among the most informed of disabled consumers, but we found that some of the items they would like to see invented and commercialized already exist and meet their needs. This suggests that despite the efforts behind computer data bases and other networks, channels of communication about assistive devices are still fragmented.

3. Many of the people involved to date, market research academics and their students, manufacturers, engineering students and faculty, have had little exposure to people with disabilities and their product needs. We believe, therefore, that a byproduct of our work with this model is to sensitize decision makers in the private sector about the economics of this market and their potential benefits from serving it.

4. Several of the potential products with smaller markets will be most inexpensively manufactured by a small contract manufacturer with OJT employees. To find these shops we met with representatives of local government and community-based organizations in the area. They pointed out that in addition to benefits to disabled consumers, they expect this project, if successful, to also have a positive effect on employment and business expansion in the community.

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COMMERCIALIZATION OF SPECIAL NEEDS PRODUCTS AT AT&T

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AT&T Consumer Products

ABSTRACT

This paper describes the process by which products are selected for inclusion in the AT&T special needs product line. The product evaluation process involves an assessment of customer needs, average customer willingness to pay, compatibility with corporate strategy, and financial fit. Challenges to the commercialization of special needs products, as well as steps to address those challenges, are also discussed.

THE PRODUCT EVALUATION PROCESS

In too many cases, products that appear to be good ideas are not successful in the marketplace. Products are unsuccessful if they do not reach enough customers, do not meet customer needs, or do not achieve the financial goals of the company. Their failure is an indication that one or more factors about the market were overlooked or misjudged.

AT&T Consumer Products has developed a formal, comprehensive product evaluation process to maximize the probability of success for new products. Essentially, a product evaluation team is charged with answering the following questions about a new product concept:

1. What are the true customer needs?

2. Do we have the product/technology to meet the true customer needs?

3. What is the average customer willing to pay for a product that meets these needs?

4. How many customers are willing to pay this much, and over what time period?

5. What is the cost to manufacture such a product?

6. Does this product fit into the corporate and business unit strategies, especially in terms of targeted market, brand association and existing distribution channels?

7. Can this product provide the appropriate financial returns to the corporation? This question is really a quantitative summary of the previous six questions.

Customer Needs The determination of true customer needs is essential to a successful product. If customers do not need it, it will not sell. Market research (such as focus groups and surveys), trade journals and other literature, market trials, sales channel input, and competitor experiences are all tools used to assess customers' true needs.

Understanding customer needs is usually the most difficult, and perhaps the most important, part of product development. In the disabled consumer market, matching technology with true customer needs can be equally difficult. Often times the solutions to customer needs (especially for severely disabled consumers) fall short of solving the entire need. The matching of a product or technology to true customer needs is therefore very important to the success of the product.

Willingness to Pay and Cost to Manufacture The same marketing tools are employed to estimate what the average customer is willing to pay for a product. The amount a customer is willing to pay must then be compared to the cost of manufacturing a unit. (Note that the cost of manufacturing a unit decreases as the number of units to be manufactured increases.) The difference between the price the customer is willing to pay and the cost of manufacturing a unit can be termed the *gross margin*. Out of this money, further deductions must be made for advertising expenses, sales expenses, distribution expenses, overheads, etc. If the net difference does not meet the financial requirements of the business, then new manufacturing techniques or new technology advances must be undertaken to reduce the cost of the product, or expense cuts in advertising or distribution must be considered. In general, the customer's willingness to pay for a product will rarely be changed.

Sales Forecast Given the average customer's willingness to pay, the price of the product, the size of the market, sales channel expertise, and consumer awareness of the product, a sales forecast is developed, usually for the first two years of the product.

Fit In Corporate Strategy All product ideas are examined for their compatibility with the corporate business strategy. Specifically, it is determined if the target market for this product is a subset of the corporate target market. For example, hearing-impaired telephone users are definitely a subset of telephone users, AT&T's major market.

The question of how often customers will come to AT&T through our existing distribution channels to buy the product is also addressed. For example, most customers would think of going to an AT&T Phone Store or

Sears if they needed an amplification device for their telephone, but it is not clear they would shop there for a hearing aid.

Finally, an assessment is made of how often targeted customers would think of AT&T as being a company to market such a product; that is, do they associate the AT&T brand with the product under consideration? For instance, a customer may not relate the AT&T brand to smoke alarms for deaf consumers.

Financial Fit As previously stated, financial fit is a quantitative summary of the product evaluation process. The financial analysis predicts how quickly AT&T can recover its investment in items such as research and manufacturing, and earn the appropriate return on the product. In the case of special needs products, AT&T has identified the return as the amount necessary to recover investment in a reasonable time frame, cover the costs of doing business (advertising, distribution, etc.), and earn enough cash to reinvest into technologies and product enhancements that provide continuous improvement in meeting the needs of disabled consumers. In simplest form, the financial equation can be summarized as:

(Gross Margin - Expenses) X (Sales Forecast) > Investment, in a reasonable amount of time.

Again, the *Gross Margin* is the difference between the amount a customer is willing to pay and the cost of manufacture. The *Expenses* are the costs of doing business. The *Sales Forecast* is a function of the size of the market, how well the product meets true customer needs, and the price of the product. The *Investment* is the cost of research and manufacturing. The amount of time to recover the investment varies with the state of the economy and by company. Once this equation can be satisfied, and all of the product evaluation questions answered satisfactorily, a product can begin the development and introduction process.

CHALLENGES TO COMMERCIALIZATION

In general, special needs products can be divided into two categories: those for consumers with mild to moderate impairments, and those for consumers with severe impairments. Amplified handsets, in-line telephone amplifiers, and Big Button telephones are examples of devices that belong to the first category. A large number of consumers shop for these products in traditional telephone distribution channels. These products appear to satisfy customer needs, at prices customers are willing to pay.

TDDs and speakerphones with adaptive switch inputs are examples of devices that belong to the second category. These are the products that face significant commercialization challenges. These challenges can be summarized as follows:

1. Although there is a relatively large population of severely impaired consumers, their needs vary significantly, creating many small (when examined by needs) market segments.

2. Although awareness of these products has increased dramatically in recent years, overall awareness is still very low.

3. Historically, providers of this equipment have not been overly successful. This raises the obvious questions:

   - Are these products meeting the true needs of customers?

   - Are the prices of these products in line with what customers are willing to pay?

   - Is the technology/product able to meet the needs of the customer?

   - Can the correct product be produced at the correct cost given the average customer's willingness to pay?

4. There is no clear definition of where severely disabled customers shop for products and if there are more cost-effective ways to distribute products to customers.

NEXT STEPS

Despite the challenges to commercialization, AT&T views this market as an extraordinary opportunity to satisfy our customers, enrich the careers of our employees and add value to our corporation. It is clear that the agenda to successfully address the needs of disabled consumers must include the following:

1. The further evaluation of customer needs, and customers' willingness to pay for the resolution of their needs.

2. The advancement of current technological capabilities to meet customer needs. It should be noted that this effort must be prioritized by the magnitude of customer need.

3. The development and execution of strategies to raise customer awareness.

4. The further development of distribution channels that effectively serve disabled consumers.

FURTHER INFORMATION

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Introduction

Sweden (pop. 8.5 million) has a unique system for the provision of assistive technology. Basically the consumer gets advice,the device, adaptations, training, maintenance, free of charge. Due to this, we may use technology and systems that are rarely found elsewhere. We can to some extent support the development of devices that may be quite expensive to buy, but that will be cost-effective in the long run. R&D in Sweden is very often supported by the government. In this paper we would like to discuss some of the recent projects.

Telematics

With the term telematics we refer to services and products by using telesystems and computers. Since a couple of years we have a special project intended to deal with all aspects of telematics and disability. The reason is that this area is very dynamic, promising many new services but may also present new obstacles if we fail to make the industry aware of issues related to access for disabled persons.

One such new service is ISDN, the simultaneous communication of voice, data and pictures at up to 64 KBit/s. There is a lot of debate in the industry on whether ISDN is already obsolete but in Europe as well as in the US, ISDN is a very important standard for years to come. With ISDN not only do we get a new generation of TDD's but also a TDD on the table of non-disabled persons. It will increase dramatically the opportunities for todays TDD users to communicate. ISDN may also offer a first, primitive videophone for sign language communication. Imageprocessing methods to give an acceptable moving picture at 64 kBit/s are being developed all over the world - also in Sweden. ISDN-terminals are being developed by many manufacturers all over the world and it is important to bring to their attention the demands for accessibility.
More examples will be presented at the confernce.

Reading disabilities

Assistive technology for persons with reading disabilities (dyslexia, low vision and motor impairments) is another important area of work. Examples of initiatives: The "Home Fax" project, where we give visually impaired persons the possibility to fax their mail and other written material to a telephone based reading-service. This concept will also be used for some deaf blind persons but the feedback will be braille (printed or computerbased) instead of voice.

The DDN (Daily Digital Newspaper) project has now resulted in a permanent such service. Every night, a full content morning newspaper is broadcasted by nationwide radio stations to subscribers and is automatically stored in a memory of a computer in the home. The information is tapped at the printing office of the newspaper The information is available by synthetic speech or braille and the typical subscriber is visually impaired but this service may also be of interest for motoric impaired persons or people with dyslexia. You can read the paper by searching for sections, headlines or key words.

We have also started up a project to give deaf sign-language users a daily video "newspaper". The issues that we are dealing with at this time is to find an effective distributing method by using TV-broadcast or cable.

In he Study Literature Project we try to find ways of better serving the needs for literature for e.g visually impaired students by using new production methods, assistive technology and new media. Traditional translation to Braille is expensive and often not done or not kept up to date (the most recent German-Swedish dictionary in Braille dates from 1911 !).

CD-roms are becoming a popular alternative storage media for text and pictures and they offer ways (speech- synthesis , braille etc) of retrieving the information for people with disabilities. Encyclopedias, dictionaries and bibliographic databases are becoming available on CD-ROM. Among the titles on the market you find a variety e.g The Telling Dictionary, Marriam-Websters Ninth New Collegiate Dictionary complete with illustrations and digitized speech and there is even a Japanese Singing Bird Atlas!

Experiences from our trials on CD-ROMS on the market today, indicates that documentation is not as good as we want it and that we sometimes had problems with the software when using several different CD-ROMs sequentially. Several screen reading softwares had problems with windows and graphics - there is a need for industry standardized codes so that the software knows how to deal with it.

Design

During the last decade we have been looking for talented designers to work in many of the established areas of assistive technology: wheelchairs, devices for children, tools for people with impairments in arms/hands etc. We want the device to be highly functional and at the same time beautiful. Professional designers have typically a very developed methodology when they approach a new task and they have proved to be very successful also in an area they did not know much about - rehabilitation technology. Some of our designers have recently been given most prestigious international awards and their work are represented in art museums eg. The Museum of Modern Art in New York.

Robotics

We are currently running a project on office workstations for motorimpaired persons. The aim is a bit different from most other projects we know about: we are only using the robot to serve people with fairly good hand function but with poor reach. The robot will take the object from a storage and place it in front of the user. The robot (we are currently using an RTX from U.K) will serve the disabled person by handling files, binders, tools, diskettes, cassettes, coffee cups etc. It is controlled from a keyboard - using preprogrammed movements and functions.

Ultrasonic Head Controlled Wheelchair/Interface
A Case Study in Development and Technology Transfer

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Abstract

The design, development, and technology transfer activities associated with the Ultrasonic Head Controlled Wheelchair (UHCW) has occurred over the past ten years. It has involved the efforts of the principal investigator as well as other researchers, students, test pilots, potential manufacturers, funding agencies, and personnel from the VA Rehabilitation R&D Evaluation Unit (REU) in Baltimore. This account briefly documents the history of bringing this design to commercial reality.

Genesis

The UHCW project began in October, 1979 at the Design Division at Stanford University where a group of five graduate mechanical engineering students were assigned the task of designing an alternative and innovative control and guidance system for an electric vehicle capable of transporting quadriplegic individuals. Their nine month effort, supervised by the principal investigator and funded by RR&D, resulted in "Smart Alec", a modified Everest and Jennings electric wheelchair outfitted with shaft encoders, electronics, a microcomputer, and numerous Polaroid ultrasonic distance ranging sensors. [Figure 1] Two of these sensors monitored the user's head position for navigation while others detected obstacles in front of, behind, and to the sides of the wheelchair. [1]

After the students graduated and went their separate ways, the project was moved to the RR&D Center where the design was refined and publicized. In April of 1981, the wheelchair was demonstrated at the annual ASME conference in Chicago. [2] In August of that year, it was reported at the International Rehabilitation Engineering Conference in Washington. [3] And in November of 1981, the project was awarded 4th prize in the Johns Hopkins Personal Computer Applications Competition in Washington, DC. At the System Sciences Conference in Honolulu, it was judged the best paper. [4]

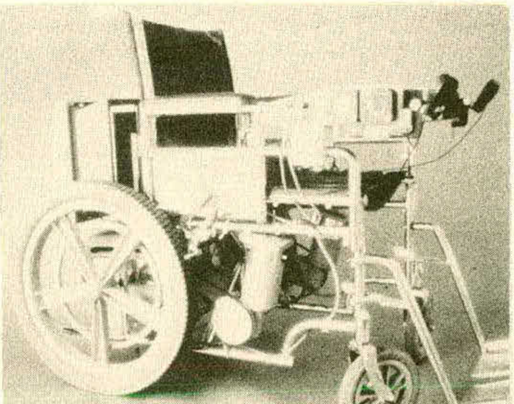

Figure 1 - "Smart Alec" Wheelchair

Despite many demonstrations of this new mobility control concept, the students' solution was far from a practical vehicle. Its deficiencies were many. The method of loading the computer program from disk storage was both time consuming and could not be performed by a disabled user. The disk drives and CRT required a source of AC power during the loading phase, which might not be available in places where the chair might travel. The software proved difficult to maintain and modify. Although these problems could not be easily corrected on the existing prototype chair, the project did show the feasibility of computer controlled mobility directed by head position and did show that the ultrasonic sensor system could detect obstacles and take appropriate action. The practical execution of these concepts would have to accomplished in a later design.

Second Generation

Since the ultrasonic head control technique appeared to have sufficient merit for further development, a generalized wheelchair interface was pursued. A proposal was submitted to and funded by the Technology and Research Foundation of the Paralyzed Veterans of America for this work. In May, 1982 the Ultrasonic Head Control Unit project was begun at the RR&D Center, its goal being the development of a second generation wheelchair control system.

With that funding, advances in computer hardware, and new developments in high level languages, a new Ultrasonic Head Controlled Wheelchair was developed by the first half of 1983. The computer's instructions were then permanently stored on a memory chip and the entire computer was powered by the wheelchair batteries. A more accurate and faster technique of acquiring head position information improved the steering and control characteristics. In May, 1983 the first disabled user test drove the new design and in June it was demonstrated at the RESNA conference in San Diego. [5] A dozen quadriplegic patients at the Palo Alto VA Spinal Cord Injury Service subsequently tested the prototype.

Documentation

In response to many technical inquiries about the wheelchair, a sixty-five page Technical Manual was compiled. [6] It contains complete descriptions of the workings of the UHCW, including schematics, wiring diagrams, computer program source code, and parts list. With this document a knowledgeable engineer in an adequately equipped laboratory could duplicate the head controlled wheelchair. In the past five years over one hundred investigators, researchers, and interested manufacturers world-wide have received copies of the manual.

In 1985, as work was progressing on a voice controlled mobile robot, modifications to the wheelchair-mounted head control unit were made to enable its use in specifying movement trajectories. This capability would allow the severely disabled user to control complex robot movements using only head motions.

Technology Transfer

Despite continuing interest in the wheelchair and ultrasonic distance ranging technology, no manufacturer had stepped forward to pursue commercial development of the design. In mid-1985, the Rehabilitation R&D Evaluation Unit (REU) was formed within the VA system. A Request for Evaluation for the UHCW from RR&D was one of the first to be received and approved by this new agency.

The proposal called for the development and delivery of four pre-production UHCW devices. These units were to be clinically tested at VA Medical Centers around the country for certification. It was not until 1987 that the funds were received and contracted to Eureka Laboratories of Sacramento, CA in a competitive bidding process. The company was initially made aware of the RR&D Center's work during a Manufacturer's Conference organized jointly by the VA and the Department of Commerce. In one-year's time Eureka completely redesigned the UHCW, taking advantage of new microcontroller technology and incorporating numerous safety and design features necessary of a production device. A packaging upgrade to improve the aesthetics was also accomplished. [Figure 2] Their initial device underwent a successful local acceptance test in June, 1989 and was delivered to REU shortly thereafter.

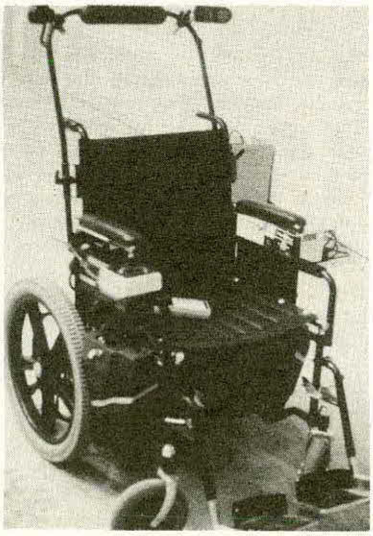

Figure 2 - Eureka's Pre-production prototype

Clinical Evaluation and Use

Under the REU program, clinical evaluation is to be accomplished at several VA facilities. A protocol has been developed by REU encompassing testing methods, questionnaires, subject selection, and data collection methods. The process is estimated to take about one year and, if successful, will result in an approval for VA physicians to prescribe the UHCW for quadriplegic veterans. By virtue of their early involvement in this project, Eureka will be in a good position to fill any orders for UHCWs submitted by the VA or other third-party payers.

Summary

Although the course of events described above are by no means typical or mandatory of other projects, they do show the need for a concerted long-term technical effort with several infusions of funds and plenty of patience on the part of RR&D Center investigators. For a manufacturer desiring to become involved in rehabilitation, early awareness of projects through interactions with the RR&D Center can lead to technology transfer rewards.

Acknowledgements

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AN EVALUATION PROCEDURE FOR ENVIRONMENTAL CONTROL SYSTEMS

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ABSTRACT

Standards were developed for evaluating and reporting on environmental control systems. Quality requirements were proposed for the use of these systems in the Nordic countries. Environmental control devices on the market in Denmark, Finland, Norway, and Sweden were tested in a laboratory environment.

INTRODUCTION

Environmental control systems (ECS) allow people with disabilities to operate home appliances and electronic devices and to perform everyday functions. An ECS consists of an environmental control device (ECD) and a number of target devices (such as lights, a radio, a television, or an electrically-operated bed) and functions (such as opening and closing doors). The ECD itself may consist of a central unit, one or more input devices, and accompanying equipment such as a door opener.

In recent years, the number of ECD's on the market in the Nordic countries has rapidly grown. If this new rehabilitation technology is not assessed, and device characteristics are not widely reported, poorly designed devices may come into common use. Users will then face increased frustration and possible risks, and health care resources will be wasted. Without expert endorsement, moreover, innovative, useful, and well-designed products may not succeed.

An evaluation of ECD's on the market in the Nordic countries has been carried out. This evaluation was part of a Nordic cooperative effort to assess technical aids for disabled people. The evaluation covered electronic environmental control devices which allow multifunctional operation and are intended for personal domestic use. Such devices include infrared and ultrasound transmitter and receiver systems, which control mains-operated appliances (such as lamps) through relay units and low-voltage appliances (such as a telephone) directly.

METHOD

The objective of the evaluation was to establish requirements for a satisfactory level of safety and usability in electronic environmental control devices. It was intended to serve as a basis for testing individual pieces of equipment and determining their safety levels.

Quality requirements

A proposal was made defining quality requirements for ECS's in the Nordic countries (1). It includes general construction and safety requirements based on the standards of the International Electrotechnical Commission. These standards were applied with regard to the special features and locations of use of the ECD (2). The proposal also contains installation requirements for the ECD and recommendations for its operation.

Evaluation

ECD products from twelve manufacturers were checked for compliance with the proposed quality requirements. The object of the tests was to determine whether the manufacturers were able to produce devices meeting the recommendations. Each product was subjected to the relevant tests specified in the proposal.

There were two parts to the evaluation process. The technical evaluation involved a general electrical safety inspection, an assessment of accompanying documents, a safety-in-use inspection, and a sensitivity test which detected any external interference caused by interruptions or variations in the mains voltage.

The functional evaluation assessed the functionality, adaptability, and expendability of the equipment, and the design and construction of the central unit, input devices, and any accompanying devices. A small group of experts, including occupational therapists and technicians, applied the proposed functional recommendations by testing the equipment in a laboratory environment. The functional recommendations highlight issues that are important to consider in each individual case when assessing the usability of an ECD.

Test report

A four-page test report was compiled for each piece of equipment. The report identified the equipment and included a technical description, a photograph, technical data, a functional description, technical and functional evaluations, and a summary. All partners in the Nordic cooperation effort received a test report for each ECD. These reports are the basis of product bulletins produced in each Nordic country.

RESULTS

There are many different ECD's available in the Nordic countries. Some of the devices are designed for simple on-off control and only work with a few mains-operated appliances. On the other hand, some microcomputer-based systems are powerful enough for comprehensive home communication and control. Several innovations have come on the market, including a microprocessor-based infrared-controlled lock system and door opener, a programmable and trainable infrared transmitter, and the use of existing house wiring (power lines) for data transmission.

In an ECD, the input devices, central unit, and any accompanying devices may communicate by wired or wireless transmission. Wired systems can use coaxial cables or existing house wiring, for example, and wireless systems can transmit via radio, infrared light, or ultrasonic frequencies. Each transmission technology has advantages and disadvantages. Whereas systems that use house wiring are simple and inexpensive to install, wireless systems are highly portable.

The technical construction of the tested ECD's is acceptable, and their operation meets the manufacturers' claims. Some devices are susceptible to interruptions or variations in mains voltage, which may prove hazardous. The mechanical strength of some input devices is not sufficient for daily use.

The deficiencies of ECD user interfaces constitute a significant usability problem. Since many devices cannot be easily adapted for individual users, their user groups are necessarily limited. Almost all manufacturers provided inadequate documentation.

CONCLUSIONS

The results of this evaluation can be used as basic technical and general information for providing ECD's to people with disabilities. In order to select the most suitable ECD for each individual, it is important to consider the user's impairment, residual functions, motivation for using technical aids, needs for environmental control, and home environment.

ACKNOWLEDGEMENTS

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Evaluation of Rehabilitation Devices: A Practical Example

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Introduction

Unbiased and thorough testing is critical when evaluating existing technologies. However, without an adequate internal and clinical review of the results, the findings of the study may become muddied or inconclusive. Evaluating products goes far beyond the physical testing involved in the assessment. From the time a technology is assigned to the primary project officer (other engineers and clinicians are commonly consulted in an evaluation) through the testing phase until the publication date, a typical evaluation goes through at least five formal in-house reviews and two rounds of review by clinical experts before a final review by the participating manufacturers. Questions do arise during review periods, and additional testing is often performed or tests are repeated to verify results.

Methods

An evaluation can be divided into five sections, namely Introduction, Criteria and Test Methods, Results, Discussion, and Ratings and Conclusions. The first phase of a typical evaluation is the Task Assignment and Subject Review. Using an evaluation of ambulation aids (i.e., canes, crutches, and walkers) as an example, the first step is the assignment of the evaluation to the project officer. Selection of the project officer is based on the relevant background or experience necessary to perform the task. Project concepts may be suggested by a coworker, hospital, or, in this case, our REC's Advisory Committee. Feedback from consultation telephone calls often guides the scope of the evaluation.

The next step is a detailed market analysis to determine manufacturers and devices that are within the scope of the evaluation. Information is often found in the Health Devices Sourcebook, through ABLEDATA searches, in The Rehab/Education Technology ResourceBook series, and by speaking to experts in the field or DME vendors. This information is supplemented by speaking with in-house consultants, searching the FDA listing of registered establishments, and looking through trade journals and catalogs.

A detailed literature search helps define the physiologic rationale and clinical indications for using a device. For example, one can determine that a walker is most often used by an elderly person with impaired balance. Other information about gait training and a history of ambulation aids is also found via the literature search. Many of the articles also identify potential reviewers. Even experts with parochial or economic interests in the equipment may be valuable sources of information. Included in the search are any relevant standards or specifications. The standards may originate from an agency (e.g., RESNA), state, national (e.g., ANSI, ASTM), international (e.g., ISO, CITECH), or military source.

Once clinical and technical consultants are contacted, they help the project officer develop the evaluation criteria (including the rationale) for these tests. The project officer must then determine the best test method for each criterion. Test methods are often spelled out in a cookbook fashion in standards. Independent development of test methods often involves weeks of design, fabrication, and calibration time.

Usually, the Introduction to the evaluation is written concurrently with the development of test methodology. A thorough introduction discusses the physiologic rationale for the devices along with alternative devices that may achieve a similar result. It also helps justify emphasis on certain specific test results from which conclusions and ratings are drawn. Writing the Introduction clearly defines the technology for the project officer and gives reviewers a background to the technology and scope of the evaluation. This section also permits the early recognition of whether or not another type of device is more suitable for the evaluation (i.e., should a wheeled walker be studied for an evaluation where the clients' greatest disability is lack of strength when carrying packages from the store? Or is a scooter a better alternative?).

Following the Introduction section, the project officer writes an outline of the criteria, rationale, and test methods for the evaluation. This draft is reviewed by a 6 to 10 member review committee comprised of medical and rehabilitation specialists, engineers, and physicians so that all of the relevant characteristics are identified prior to the first complete draft. Feedback from the outline helps to form the Preliminary Evaluation Criteria and Test Methods.

Manufacturers are contacted as early as possible, but only after the project officer is fairly well versed with the basic technology. Manufacturers can be quite helpful discussing advanced issues about their products. The most productive contacts at these companies are generally high-level managers (e.g., president, chief engineer, product manager). If the contact does not have the authority to make decisions related to the evaluation, then delays and confusion may result.

The criteria, rationale, and test methods are the basis of the final evaluation report. The Preliminary Evaluation Criteria and Test Methods, or T-0 draft, is submitted to the review committee. A meeting follows this review to discuss any comments, questions, or additional tests relevant to the evaluation. This initial staff review helps to educate the reviewers about technical issues associated with the product. It is the responsibility of the the project officer to raise all known clinical and technical issues at the T-0 meeting. Resolution of some issues requires input other than laboratory testing, and the evaluation is often accompanied by input from clinical specialists or user surveys. It is essential to investigate these issues at an early point in the evaluation process, as user surveys often require a few months more than the testing period in order to compile the results.

During the T-0 meeting, the review group will try to reassess the clinical, diagnostic, therapeutic, safety, and economic importance of the type of device and try to identify alternative devices or methods. Following the meeting, a working schedule is established, identifying all short-term milestones through the next meeting, when results and findings (T-1) are discussed. The T-0 draft is revised after the meeting, adding all of the comments from the review committee, unless they were discussed with the reviewer or the Technical Director.

The revised T-0 draft is finally sent to manufacturers and clinical and technical (outside) consultants for review. Concurrently, each manufacturer is sent a standard equipment request letter, requesting the device and a supply of disposable equipment for the evaluation and the date it is needed in order to begin testing. We request the loan of a standard piece of equipment taken off a stock shelf.

The manufacturer review period and the time spent waiting for devices to be sent is used to design test apparatus or to make arrangements for test equipment or test facilities. For the ambulation aids evaluation a twin parallel pneumatic cylinder static and dynamic loading frame was designed and built. The stability test platform and slip testing surfaces were built specifically for this evaluation. Scales and other common measurement instruments are already available in the laboratory and require little set up time.

Clinical tests are usually performed at affiliated and nearby hospitals under the supervision of the project officer and hospital clinical personnel. Some tests require the informed consent of the patient or client. These test are closely reviewed by the review committee, clinical consultants, and, often, legal counsel. Clinical studies require a separate schedule for testing. The Institutional Review Board of some hospitals will not allow tests to be performed using patients until each device passes at least the minimal safety tests in the laboratory. Time must be allotted for in-service training of hospital personnel and test volunteers.

Devices are inspected for possible shipping damage as they arrive. The project officer then catalogs each device for inventory control purposes. With the number of canes, crutches, and walkers, it is easy to create an inventory problem if the devices are not properly labeled and stored. Some tests should be performed early, before reading the manual. Manuals are often lost, and the best device may become worthless if its use is not intuitive to the general user. A comprehensive characteristic table is easily filled out as the devices are being set up and tested.

During the testing phase, manufacturers should routinely be given updates if there are any significant findings involving their products. By not waiting until the end of an evaluation to contact manufacturers about potential problems or shortcomings, the project officer can benefit from manufacturers' ideas. Often, the manufacturer will begin modifying a product at this time. The result is a final report that may state that "Manufacturer X's product failed this test, but we believe that modifications that we have seen will alleviate the problem (or enhance performance)." Manufacturer cooperation is an important factor in the evaluation process. Lack of communication during the testing phase does not effect the final results or ratings of units, but it may delay the evaluation's completion.

The initial draft of the evaluation (T-1 draft), including the Introduction, Test Methodology, and Results, is submitted to the review committee following testing. The project officer must often modify the Test Methodology section according to the natural evolution of each test. For example, in the evaluation of ambulation aids, the device used for dynamic loading was modified numerous times, although the test criterion did not change. Writing some portions of the Description of Units and Test Results sections is easier during testing. It is often difficult to elucidate the more subtle points months after the test is performed. The committee reviews the T-1 draft for at least one week before the next formal meeting.

All comments and questions by the committee are addressed in the T-1 meeting. The goal of this meeting is for the project officer to leave the room with an idea of how the individual units will be rated. Additional tests must often be performed to clarify some results or touch on new areas that evolved from other tests. The T-1 draft is revised many times until all of these issues are resolved, at which time the project officer writes a T-2 draft. Generally, by the T-2 draft, there is a consensus among reviewers on how ratings should be assigned.

The T-2 draft is also distributed to the in-house review committee, although it is not usually followed by a meeting. Relatively few changes take place between the T-2 draft and the first draft sent to outside reviewers and manufacturers (T-3). By the time the manufacturers see the preliminary results and conclusions, the draft has gone through at least three independent levels of review.

Changes to the draft are incorporated following the manufacturers' and outside reviewers' comments. All comments are addressed by the project officer, and, if the reviewer requests a change that will not be made, the reason is discussed so that the project officer may explain the collective opinion of the laboratory. The finished technical document is the T-4 draft. At this point, the evaluation is ready to go through the strict review of the Technical Director to make sure that all technical issues have truly been resolved.

The final editorial phase of an evaluation usually lasts about three months following the T-4 draft. Therefore, the completed evaluation may not be published until a year or more after the initial contact with manufacturers and clinical reviewers. The key to a successful evaluation is the strict attention paid to the documentation, testing, and review phases.

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Follow-up and Videotape in Rehabilitation Technology

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ABSTRACT

A follow-up system that was initiated in the summer of 1989 at the Rehabilitation Engineering Center (REC), Children's Hospital at Stanford has used videotape as a means to transfer educational information to device users, their families, therapists, teachers, aides, and attendants. Preliminary results show that clients and their families find the videotape useful and that over half of the clients have shared the videotape with their therapists and teachers.

INTRODUCTION

As part of the follow-up system that was presented at the 1989 RESNA conference and addressed in those Proceedings "Implementation and Follow-up of Rehabiliation technology", videotape has become a valuable tool in the delivery of information to the client, family, and associated health professionals.

Videotape alone is not a complete system by which a follow-up program should be governed but it can act as a cost effective and efficient means to impart valuable information.

METHOD

Part One: Five devices that are regularly fabricated and/or delivered at the Rehabilitation Engineering Center at Stanford, were each featured in a five to ten minute videotape. The filming of each of these segments was conducted at the REC with the help of a small local videotape production company.[1]

Each device (Touch Talker with Minspeak, manual wheelchair, orthopedic seating system insert *OSS*, thoracic-lumbar-sacral-orthosis *TLSO*, and a below knee *BK* prosthesis) was described and the use, care, and maintenance instructions demonstrated by the respective health care professionals. Each segment was edited onto separate videotapes and a generic introduction and conclusion were added. Several copies of each of the five 3/4" inch videotapes were completed for distribution.

Part Two: After the creation of a generalized videotape (part one) a more personalized and client-specific approach needed to be added.

As part of the entire follow-up system referred to previously, the project occupational therapist participated in 60 delivery sessions (with client, family, and clinician) where one of the above named devices was delivered. In 20 of those deliveries, a videotape was made of the clinicians "wrap-up" session with the client. More personalized instructions about the device were reviewed. This brief segment was then copied onto the more general videotape (part one) and mailed to the client within three days.

To evaluate the usefulness of the videotape among the client and family, questions have been included in a "Phone Call Follow-up Form" which is used at 1, 3, 6, 9, and 12 months after the delivery of the device. The questions focus on who has seen the videotape (client, family, friends, therapists, teachers, etc.) and how many times it has been viewed. Obviously, the question of greatest concern is how helpful was the videotape for the parties just mentioned? Did it make the acceptance easier? Did it simplify the processes involved in caring for and using the device? Was the information valuable for therapists and teachers?

RESULTS

Preliminary results show that approximately 50% of the clients and families who received videotapes shared them with therapists or teachers. The majority of clients have found the tape useful, especially those who felt overwhelmed during the delivery process. Those clients who have previously received similar devices from the REC did not find the tapes as useful.

The majority of families feel that at the time of delivery, the information from the clinician clearly exceeds the capacity of their memory. The videotape allows the client to "experience" the delivery session again at a pace they can digest. This additional education adds to a better acceptance and more efficient use of the device.

DISCUSSION

The costs of providing videotapes as part of the follow-up system can vary greatly as determined by the number of "target devices" filmed, the quality of filming and editing, and the number of clients who will receive the videotape. For the purposes of this study, only 20 clients and families received a videotape which cost approximately $25.^{00} per videotape.

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[1] Personalized Broadcasting Service, Mtn. View CA

It is anticipated that once the final results for this study have been determined regarding the usefulness of the videotapes an average of 120 tapes annually would be distributed at a cost of $4.^{00}$ per videotape (plus the cost of the blank videotape) for the first year. Additional years of usage would lessen the overall cost of the videotape.

CONCLUSION

Based on the preliminary results of this study, the use of videotape as a means to provide effective follow-up has been shown to be efficient has the potential to be extremely cost efficient.

The obvious benefit to a strong follow-up program aids the the user and their family. Other significant beneficiaries are the therapists, teachers, aides, and attendants who can learn the specific details of an assistive device and how it can interface with the user. Finally, the clinicians and technicians who fabricate and fit the device are provided with a tracking tool that visually depicts the progression of the client and their use of the device.

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A DEVICE FOR EVALUATING AND/OR TRAINING TELECOMMUNICATION SKILLS

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ABSTRACT

The authors describe a device designed to evaluate an individual's ability to perform the tasks required of a telephone operator/ receptionist, as well as train an individual to perform those tasks. The major objective in the development of such a device is to enhance the employment opportunities of persons with disabilities. The system is microprocessor controlled and uses commercially available peripherals to simulate the tasks required of a telephone operator/ receptionist and/or information clerk. A key feature of the device is that, once programmed and initiated, it is capable of running with minimal supervision.

INTRODUCTION

An agency, which is involved in the evaluation of the employment potential of persons with disabilities, desired information relative to an individual's ability to function as a telephone operator/receptionist. The agency required that the device be user friendly, be capable of testing simple to complex telephone operations, and not require a great deal of staff time to operate the device.

METHODS

Equipment. A market search was conducted for a telephone system which would be representative of those frequently used by businesses requiring an operator/receptionist. An AT&T 34-button telephone, which operates on the Merlin system, was selected since this system is reported to hold the greatest market share (29.9%) for the office network market [1]. Other equipment consisted of two standard tape players purchased from Radio Shack and two cassette tapes, one 30 minutes and one 90 minutes in duration. The first tape player plays a 30-minute cassette tape of simulated phone calls. The second tape player utilizing a 90-minute cassette tape records the test/ training session for evaluation purposes.

The electronics package that interfaces all peripheral equipment together (telephone and tape players) was designed to make real-time decisions based upon the feedback available from the peripheral devices. Such decisions might include: instructing the phone to ring and turning on or off the tape player that plays the tape of simulated phone calls. In order to perform these and many other tasks, a microprocessor-based design was implemented. The complete evaluation/training workstation is shown in Figure 1.

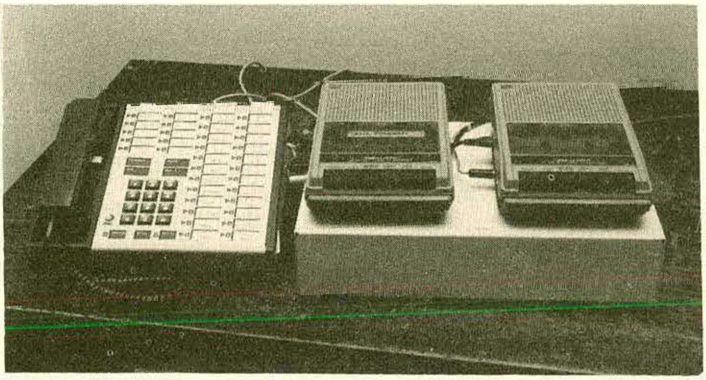

Figure 1
Telecommunication Evaluation and/or Training Workstation

Operation. A 30-minute program cassette tape of simulated telephone calls is designed by the user to meet the needs of a particular setting. The simulated phone calls are tape recorded and numbered. The following system parameters are programmed: beginning simulated phone call number, ending simulated phone call number, time between phone calls, time allowed for the operator/ receptionist to greet the caller, and an on/off auditory feedback of errors. Based upon the cassette tape of simulated telephone calls, the system is programmed with the following information: the number of the phone call on the cassette tape, a code for the type of phone call (direct ring or transfer required), the telephone line button to ring, and the desired action of the operator/ receptionist. This programming sequence is performed for each simulated telephone call on the program cassette tape. All information is programmed using the AT&T telephone.

RESULTS

The device designed has the following features:

- microprocessor controlled
- utilization of standard business office equipment and standard cassette tapes and tape players
- user-friendly via programming menus for system parameters and phone call information
- storage capability of more than 500 pre-programmed call instructions
- variable delay between phone calls from no time between calls to four minute intervals
- job requirements can be defined by user: multiple offices/ departments, type of calls to be handled, (transfer, hold, etc.), and clerical duties required
- minimal supervision required
- capability of use as an evaluation/screening/training tool

Preliminary results show the device to have the capability of providing information on communication skills, short-term memory, decision-making, message-taking abilities, accuracy in transfering calls, and the number of calls handled per hour.

CONCLUSION

A telephone operator/receptionist must appropriately handle many incoming telephone calls per hour. Persons with disabilities and with good verbal abilities are often suggested for positions in telephone operations. Employer attitudes can often prevent qualified job candidates with disabilities from an opportunity for employment in such positions. A device which can train persons to be qualified telephone operators/ receptionists and/or information clerks, or prove competency in the skills required for such positions, would enhance employment opportunities for persons with disabilities.

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A MOTORIZED LIVING AID FOR PERSONS WITH ARTHOGRYPOSIS

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ABSTRACT

The ability to perform daily rituals in hygiene, dressing, and grooming is taken for granted. A person afflicted with arthogryposis must too often rely on family and paid assistants to help with these basic, personal needs. This paper describes a motorized frame allowing an arthogrypotic the freedom to care for himself.

INTRODUCTION

Of every thousand disabled children, three (1) are born with arthogryposis, a neuro-muscular disease affecting joint movement. There is incomplete development of the muscles moving involved joints and degenerative changes of motor neurons innervating the muscles (2).

The knees and elbows of those afflicted are severely limited, while hip and shoulder joints are limited slightly less. The lack of flexion in these joints presents a severe problem for performing daily living skills around the head and upper trunk areas. Namely, brushing teeth, brushing hair, shaving, applying deodorant, and similar tasks. Several commercial devices exist for specific tasks, but none for comprehensive, independent, upper body care.

DESIGN CONSIDERATIONS

The motorized frame was designed around a specific client, Mike. He is a 19 year old who has adapted particularly well to his affliction. He has good hand function, allowing for manipulation of eating utensils, tools, paintbrush, etc, at arm's length. Hip flexion is adequate for eating in a standing, bent-over manner, but shoulder rotation limits arm movement to ~20 degrees from vertical. The only thing which prevented Mike from an independent living environment was the lack of ability to perform personal hygiene and grooming as described previously. His personal goals included a state college away from home, which would not be possible without some sort of living aid.

Mike's hand control should be utilized in operating any device, which would be used for transporting the hygiene/grooming appliances from hip to head level. The frame should be effective, rugged enough for everyday use, adaptable to many appliances, economically priced, and if possible attractive for use as a household item.

METHODS

An AC motor provided the drive mechanism for the frame. For the rpm range required (around 1500), the only motor available was a 220 V input, requiring a 1 kVA transformer for adequate power.

1/2" threaded rod was coupled to the motor shaft and acted as a system worm gear. Two 1/2" couplers were threaded onto the rod, and a 1" aluminum flat bar assembly clamped to the couplers. The assembly was stabilized and kept from turning with a 1/2" smooth rod placed 8" forward of the threaded rod.

A toggle switch reversed the CW and CCW rotation of the motor, and the corresponding vertical motion. A larger, momentary lever switch activated the power for motor drive. All switches were mounted at arm's length where Mike could effectively operate them.

A pine block was mounted onto the aluminum assembly, bored out in a rectangular shape. Each handheld appliance was fitted with a thermal plastic socket and mounted on a piece of pine strip to fit easily but firmly into the wood block. When required, each appliance (razor, brush, etc.) would be placed into the block and raised to the desired level.

The entire motor system was finished

in a oak and black plastic case, meeting the requirements for attractiveness in the home. All motor workings were contained within the case as an additional safeguard. A 110 V outlet was included on the case exterior for recharging an electric razor or toothbrush.

DISCUSSION AND CONCLUSIONS

The developed framework solved the problem of independent, personal care in this case. It was perhaps not an elegant solution, but workable, economic, and rugged, therefore a functional piece of equipment.

The case was strong enough to mount on a wall, and made to fit standard stud spacing. It was easily expandable for different appliances by the mounting mechanism. Each additional appliance need only to be mounted on a furring strip to slip into the block. The Polyform sockets for original items were made so these could be replaced when worn out (especially toothbrush).

The system was not without development problems. The transformer added significantly to the weight of the finished frame and is not suggested for anyone repeating the project. An effort should be made to locate a 110 V motor with the same rotational and power requirements. The aluminum assembly would occasionally bind against the stabilizer rod, halting the motor. A spray graphite grease aided this problem and should be applied regularly.

Electrical safeguards to limit vertical travel were not installed for economic reasons. The client assumed responsibility for not overextending the travel limits and jamming the assembly. For Mike, this was realistic as he is a conscientious user. In another case, microswitch limits may have been necessary. He was given trouble-shooting instructions in the event of a machine jam.

The motorized framework was completed in September 1989, and has been in use every day since then. The physical limitations from arthogryposis were overcome with a relatively low tech intervention. Mike and others with similar afflictions may need only one custom device to make the difference between dependency and a world of personal self-care.

ACKNOWLEDGEMENTS

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NEW USES OF VIDEO TECHNOLOGY FOR TRANSDISCIPLINARY SERVICE DELIVERY TEAMS

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ABSTRACT

This paper describes multiple applications of video technology to enhance the delivery of technology services in geographically dispersed states, particularly when transdisciplinary teams are needed.

INTRODUCTION

Today the delivery of quality technology services often requires a well-orchestrated technology team. The team may include a number of specialists, the consumer, parent or advocate, a public or private agency representative, and one or more equipment suppliers. Increasingly, more people with multiple and severe impairments need technology services tailored to unique needs at school, work, or in the home. In geographically dispersed states, the shortage of trained specialists who can address these needs is particularly acute. Video technology can be used to build regional transdisciplinary technology teams, document needs for devices and services, and develop case studies of both successes and failures of technology applications.

BACKGROUND

Georgia is a predominately rural, geographically dispersed state with a particularly acute shortage of trained practitioners. Yet, like many other states, there is a growing number of clientele with multiple and severe impairments who need a highly specialized technology team. These clientele require technology services in customary settings.

In response to these needs, Georgia established a statewide program of technology assistance for adults with disabilities in 1989. This program combines with expertise of a number of public and private organizations strategically located throughout the state in a consultative service delivery partnership. This statewide technology team is discovering many benefits of using video technology to assess and document unique case requirements for technology assistance.

METHODS

In 1989, a statewide technology assistance team to serve adults with disabilities was identified. Technologists were identified in eight areas of the state by the local area and blended the expertise of engineers, rehabilitation specialists, and occupational therapists. Technologists represent three major universities (two public and one private), a hospital program, and several highly specialized consulting firms.

The statewide team is referred to as the Technology Access Program (TAP), and offers a cooperative, consultative program of service delivery capitalizing and building upon the strengths of each local area TAP provider.

Individual TAP providers lack the breadth of experience and knowledge base about assistive technologies to solve many technology problems. However, the statewide TAP team and the seasoned product search and solving experience of one TAP provider has resulted in a suitable level of competence to solve most technology-related problems.

When a request for technology assistance is received, the local TAP provider determines whether the presenting problems will require transdisciplinary team intervention. Video recording is done, if possible, at the first site visit to involve other team members as soon as possible.

The TAP provider and an agency representative make this initial visit together so that the TAP provider can interact with the client during taping. A handheld VHS recorder and tripod, and some experience in using the equipment, are essential requirements. Obviously, there are situations where the client does not wish to be taped even after careful explanation of the purpose and intended audience. Release forms for the video document are completed during this visit.

After taping, the video is sent to TAP team members who will be involved in the case. The tape may be viewed and discussed at a team meeting or sent to the TAP team in different locations. Subsequent questions and ideas are explored and a plan for delivery of technology assistance services is developed with client participation.

Subsequent tapings can be made, as needed, to document progress in using equipment, a procedure or technique; visual feedback to the client to show progress and performance, to heighten the client's awareness of equipment use, and to remediate problems and reinforce acceptable performance.

With written consent, tapes can be used for training technology teams throughout the state. This case study approach offers a method of building a broader base of knowledge about actual technology problems, the team process, solutions, and benefits as shown by the user in customary settings.

RESULTS

This technique is being used in Georgia in situations where the TAP provider has identified a need for transdisciplinary team consultation. Following use of this method, TAP teams, advocates, and several equipment distributors have independently commented on the efficacy of this method -- time is saved by transdisciplinary team participation and visual documentation of problems. In one case, the client's job (duplicating tombstone rubbings to 1/64" accuracy using a computer puck - the client was visually impaired) was so unusual that tape captured the job requirements and other details which otherwise would have required lengthy explanations and follow-up calls to gather additional information.

DISCUSSION

This promising application is new and requires further study to determine outcomes, cost factors, and actual taping procedures. It is relatively easy to film too much detail. A task analysis system for filming critical elements is needed.

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FORMALIZING THE EDUCATION PROCESS
An Undergraduate Course for Occupational Therapists

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INTRODUCTION

Education for technology service providers is critical. In the application of rehabilitation technology, consumers have a right to receive technical services from qualified professionals. But what constitutes qualified? And how do we ensure that all service providers who function as team members in a service delivery program are qualified? RESNA's Quality Assurance Committee is beginning to deal with this very large issue. A clear need exists to have professionals in the field who are knowledgeable enough about technology applications to determine if:

1. their client would benefit from using a technical device
2. the technical device should be provided by the treatment professional or a referral be made to a technology specialist.

The assumption about an occupational therapist (OT) is that all graduating therapists have knowledge of what technology is available to assist clients in achieving their educational, vocational, or functional daily living goals. However, although most OTs are familiar with non-electronic ADL devices and they have some basic information about upper extremity prosthetics, orthotics, and wheelchairs, few are really familiar with the total scope of assistive technology, including low and high technologic devices, light and heavy technologic devices, non electronic or electronic technologic devices. We haven't even settled the terminology yet.

METHOD

A unique opportunity presented in 1987. A new undergraduate program in Occupational Therapy was being developed with student enrollment beginning in the Fall of 1988. In planning the curriculum, an effort was made to utilize the expertise of the staff of the UT Rehabilitation Engineering Program (UTREP). The OT curriculum director requested a course be developed entitled Occupational Therapy Applications of Contemporary Technology. It was to be a five credit hour, compulsory undergraduate course presented during the last quarter of course work before affiliations began.

Requests for outlines of existing university courses were solicited to help in content planning. All obtained were either partial, elective post-graduate or graduate level courses. At the time, to our knowledge, no single undergraduate curricula was available to serve as a model course The goal of the course was to create a general comfort level in high technology application, a knowledge of information and referral sources and the appropriateness of client referral for actual technology services.

The course outline developed by UTREP staff stated that it would focus on the principles and application of assistive technology as used in occupational therapy practice. As technology intervention is rarely the expertise of one professional, multidisciplinary interaction was to be stressed with the roles of the various professionals such as rehabilitation engineers, speech pathologists, and educators, being explored. The course would provide an overview of both low and high technology applications but the focus would be on high technology in such topics as seating and mobility, augmentative communication applications, ADL devices, environmental control technology and computer access. As the technology itself is rapidly changing, the focus of the course would be on the principles of evaluation/ training/follow-up in the use of assistive and rehabilitation technology. Information sources available which the occupational therapist could use in finding specific technological devices and systems to meet individual client needs would be thoroughly discussed. Generic categories of devices would be presented with specific examples illustrated by case study format.

Course content included the following topics presented over a twelve week period.
First we addressed definitions, an overview orientation to the application of assistive technology in occupational therapy, history of the field of rehabilitation engineering and the team members involved in possible service delivery models. The location and usage of information sources including printed, visual and electronic were presented early in the course to assist students in completing projects assigned. Seating and positioning were presented next as a prerequisite for the assessment of optimum motor control. Mobility followed naturally from the seating lecture. There was a need to discuss access strategies with the mobility section but the full lecture on access technology was coupled and reinforced with the lectures on augmentative communication and computers. Other areas of technology involved in daily living such as transportation and environmental controls. The integration of technologies was discussed. Finally, strategies and applications of cutting edge technologies such as functional electrical stimulation (FES),myoelectrical applications and computer aided design (CAD-CAM) were presented. In all cases, the stress was placed on client centered technology application. Specific pieces of technology were discussed only to illustrate case management or application strategies. Projects

requiring students to locate specific devices and document their price, function, etc., were used to ensure that they could in fact locate specific devices for clients when they became practicing therapists one year hence or at a future time in their careers.

Classes were divided into lectures and laboratory experiences. Two, one and one-half hour lectures and one four hour laboratory were taught each week. The multidisciplinary nature of our staff created the opportunity for team teaching. The course coordinator (an OT) attended all lectures and laboratory experiences to ensure the OT role was stressed especially in the lectures taught by non-therapists such as engineers, speech pathologists, prosthetists, and vendors/manufacturers . She provided continuity for the students and prevented duplication. Lab experiences offered hands on opportunities to use, fabricate, install and manipulate equipment. Clients were invited to participate in several of the labs to add reality to the learning experiences.

EVALUATION RESULTS

Student evaluations reported that the course, although more difficult than expected, certainly met the stated objectives of providing a level of comfort with the application of high technology and presented an overview of the scope of technology application in occupational therapy practice. Students were frustrated by the lack of a comprehensive text. They felt that four hour labs were considered too long. In all, they found the course interesting and informative. They all stated that it was one of the few courses in the curriculum that helped them pull together the concept of intervention from beginning to end.

Staff found that the students had a lower level of experience with actual clients than they had anticipated which forced them to lower the level of presented material. For example, part way into the lecture on seating, therapy faculty were discussing the goals of seating when it became obvious that the students did not understand what was meant by specialized seating. The lecture to explain the terminology and client needs for adaptive seating in general was modified before continuing with the seating goals for persons with specific disabilities. Faculty was also frustrated by the lack of a basic text. Faculty found the four hour labs to be too short for the amount of information they wished to present. They were also frustrated by the students lack of experience with persons with disabilities. Finally, although the teaching faculty had worked together clinically for years, team teaching was a new challenge.

Based on our experience, recommendations to those planning courses with technology application are as the focus follow. Provide a course with a broad perspective. Students will learn the specifics of installation of an Adaptive Firmware Card when they need to but they must know about positioning and access selection principles if their clients are to be provided with a comprehensive service.

Plan to teach the course during the last quarter of undergraduate training so that the students know as much about persons with disabilities as possible.

Make no assumptions about minimum knowledge base. The course work will need to be tailored to their inexperience and cannot be at the same level as continuing education for practicing therapists.

Stress information and access to resources and the principles of the application of technology. A course focusing only on devices will leave the students with information that will soon be out of date.

SUMMARY

The course is to be provided in future years as part of the undergraduate curriculum. The professionals already providing services in the field of assistive and rehabilitative technology are attending continuing education programs and participating in the few apprenticeship opportunities. The graduates of the future should enter the field with a higher level of basic training and with a higher comfort level of applying high technology. We have provided an entry level course which provides a strong overview perspective of assistive technology. It is felt that this type of content is essential before the introduction of courses on specific topics in order that professionals have a broad basis on which to begin their professional careers.

ACKNOWLEDGEMENT

Special thanks to Susan Johnson Taylor, Lynn C. Monahan, Douglas A. Hobson, Catherine George, and guest faculty.

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ADAPTIVE TECHNOLOGY TRAINING; A TEAM APPROACH

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ABSTRACT

If an assistive technology team is bogged down in conflict and misunderstanding it will not function effectively and the consumer will not be served. Our experience in training rehabilitation counselors and engineers together has pointed ou significant issues in adaptive technology team building. Issues of differential status, communication styles, turf and modes of creative work are central. Different concepts of "real work" and informed decision making may also influence the way different team members interact. Our experiences with students may prove useful for other trainers and professionals.

TEAM WORK

Super Bowl and World Series fans know it when their teams are hot, and when they're not. Winning teams have excellent players in all positions. Players are coached to perform well with each other. The team works collectively to reach a common goal. They recover when something goes wrong. A losing team may not have good players in all positions. Poor coaching may result in the players not performing well together. Individual star performances may take precedence over the common goal of winning. A losing team is easily discouraged. Teamwork is as important in service delivery as it is on the playing field.

Matching a disabled consumer with needed technology is a complex process. The technological, financial, emotional, and medical needs of the consumer must all be addressed. If any of these needs are ignored, then optimum adaptive technology services will not be delivered. The diversity of skills required to address these needs is hard to find in one person. A team is usually required. Assembling individuals with isolated areas of expertise does not guarantee success. An uncohesive adaptive technology team will do no better than an athletic team that has good individual players and poor coaching.

Our experience in an interdisciplinary adaptive technology training program has pointed up significant issues in team building which may prove useful for other trainers and adaptive technology service providers.

ENGINEERS AND COUNSELORS - DIFFERENCES

Without getting into a "chicken and egg" argument as to whether one's personality predetermines choice of profession, or whether professional training shapes one's personality, it is clear that counselors and engineers are very different from one another.

Status Differential - Our society values technical services more than human services. This is reflected in a pay differential between counselors and engineers. Engineers are also the final decision makers with regard to technical issues. Rehabilitation engineers are rarer than counselors. They are often placed in a consultant role which brings with it heightened status.

Turf - Turf concerns territoriality. While delivering services, counselors and engineers may have to step into each others turf. Power shifts as they move back and forth. The world of technology is the engineer's home turf. The visiting counselor will be inclined to defer to the host. The engineer graciously permits the counselor to enter, but it is clearly the engineer's house.

Because engineers are primarily concerned with technical solutions, they may not appreciate the counselors' turf. Counselors control the purse strings. Counselors manage case service funds for a large number of consumers. Because of limited finances, counselors may not allow engineers to select expensive optimal technical solutions. This may lead to adversarial interaction.

Mode of Creative Work - Counselors and engineers deal in different currencies. Engineers' high-level creative work is performed in the realm of visual images and abstract mathematics. Counselors' high-level creative work is in the realm of verbal and non-verbal communication. Therefore, exchanges may break down.

Communication Styles - Engineers are more likely to be economic in their verbal communications. This may relate to their greater use of visual imagery and mathematical symbolic representation, as well as basic personality factors. Counselors tend to be very verbal. This probably relates to their constant use of words to interact with their clients.

This difference in communication style is also reflected in written work. Engineers' technical report writing style is in marked contrast to the more narrative case studies produced by counselors.

Concepts of "Real Work" - Although both disciplines solve problems, the end results are very different. Engineers' creative problem solving results in tangible products. Counselors' activities focus on interactive processes intended to result in their clients' improved "adjustment". Therefore, while counselors' easily see the outcome of engineers' work, engineers have a much harder time appreciating the nature and value of counselors' work.

Informed Decision Making - Central to our training is a consumer driven model. In this model, the professional acts as a consultant to the consumer, who is in control of the service delivery process. If a consumer quickly rejects suggested technology, the engineer may, just as quickly, suggest alternatives. Engineers are traditionally taught that "the best way to have a good idea is to have lots of ideas". Counselors are more likely to consider emotional factors contributing to the negative response. Is the consumer fully aware of the personal implications of using the suggested technology? Does the technology seems to conflict with the person's values? Counselors may want to explore these areas with consumers before feeling satisfied that an informed decision has been made. This in no way negates the consumer driven model. The decision is still ultimately the consumer's, but the counselor may take longer to get there.

ADDRESSING THE PROBLEM

Our experiences in conducting an academic adaptive technology training program confirm our hypothesis that the differences between counselors and engineers must be addressed for successful functioning of an interdisciplinary team. Interdisciplinary work in the field often suffers if these differences are not addressed.

Our training deliberately fosters effective interdisciplinary work. Engineers and counselors are taught together in several classes. We offer sessions in which counseling and engineering students are separated and introduced to the fundamentals of each other's disciplines. We place them on interdisciplinary teams in which both disciplines work together to solve consumers' problems. Despite these efforts, we have encountered some of the previously mentioned difficulties in cross disciplinary work. Addressing the issues discussed in this paper is part of our attempt to remedy these problems. We are beginning to utilize an interdisciplinary panel of former students to heighten the sensitivity of present students to these issues and challenges.

CONCLUSION

We believe that many of the problems evident in our an academic training program are replicated in the "real world" work of interdisciplinary adaptive technology teams. More and more interdisciplinary work will be attempted as the field of adaptive technology grows. Awareness of these issues, and appropriate remedial action, are necessary to insure that our field produces teams of winners.

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DRIVING ADVISEMENT SYSTEM: A QUASI-SIMULATOR WHICH ELUCIDATES COGNITIVE PREREQUISITES FOR SAFE DRIVING

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Abstract

The Driving Advisement System (DAS) is a quasi-simulation of driving implemented in specialized software and hardware for IBM- and Apple-compatible computers. It is designed for use by trained rehabilitation professionals to assess and advise persons with known or suspected brain injury about whether they have the cognitive prerequisites for safe driving.

Introduction

The Driving Advisement System was designed to simulate key aspects of driving in such a way as (1) to permit objective and quantitative assessment of essential cognitive abilities and (2) to demonstrate these findings to would-be drivers clearly and convincingly, hopefully enabling them to make an appropriate decision about driving.

Driving is a complex performance which requires both skill and judgment often in limited time. The computerized protocol allows precise control of dynamic displays and measurement of response times accurate to hundredths of a second.

Immediate feedback includes graphic displays of performance relevant to the median and outer limit (96%tile) of the safe driver norm group.

Judgment is captured objectively by (1) asking for self-estimates of current abilities relative to the "average" and "worst, yet safe" drivers and (2) including the self-estimates on the norm-based performance graphs. Persons who overestimate their abilities, especially when those abilities are somewhat compromised by disability, age, or other condition, lack a basis for making compensatory adjustments and defensive driving.

Hardware

The DAS requires an Apple IIC, IIe, or II-GS, or IBM-compatible computer and printer. IBM systems must have a game port and at least CGA graphic capability. A steering wheel and three pedal assembly, connected to the computer through an interface box attached to the joystick (Apple) or game (IBM) port, are used for input. Switches (for pedal responses) and analog devices (for steering) may therefore be easily substituted to assess performance with adaptive equipment. Tension on the steering wheel can be adjusted to determine the role of that factor, bearing ultimately on the advisability of power steering.

Software

Written in BASIC with machine language subroutines (Apple) and compiled (IBM) for efficiency, the programs have been checked carefully for accuracy of timing routines.

The DAS protocol was designed by a neuropsychologist to maximize apparent validity (to convince the examinee of its relevance) while permitting rigorous analysis of underlying abilities. The three main sections of the protocol are background information, pursuit tracking, and reaction time measures.

Pursuit tracking (ON THE ROAD) requires the use of the steering wheel to maintain a steady central position on a changing roadway. Average deviation from center, as well as the standard deviation of relative position, are reported as indices of lateral bias and inconsistency in this eye-hand coordination task.

The reaction time measures all differentiate choice (decision) and execution (movement) components. There are three tasks of increasing complexity, beginning with simple reaction time

Driving Advisement System

(BRAKE). A two-alternative reaction time task (DECIDE) lays a foundation for the most demanding task (INHIBIT) in which the established rules are to be reversed on trials preceded by a "reversed" signal.

A Report Generator is automatically invoked at the conclusion of the procedures. Results are displayed graphically in a form which facilitates discussion between the clinician, the prospective driver, and concerned others (family members, other therapists, etc.). The printout is designed to simplify the recording of a clinical summary (verbal and ratings) and recommendations.

Findings

Formal psychometric studies are beyond the scope of this paper, but have been completed. Normative data are now available for over 70 safe drivers of different ages. Concurrent validation shows the DAS compares well with other measures: Porto-Clinic/Glare, Driver Performance Test, Doron Driver Analyzer simulator, comprehensive evaluation and driving a year later.

Clinical experience with the DAS shows that this safe and relatively economical system can make an important and unique contribution to pre-driving advisement, a very serious issue facing those in brain injury rehabilitation. The DAS is unique in its emphasis on higher-order cognitive functions, e.g., mental processing efficiency as task complexity increases, impulse control, facility in adjusting to changed circumstances, ability to sustain consistent performance, frustration tolerance and judgment.

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        COMPUTER PROGRAMS FOR COGNITIVE REHABILITATION VOL. 6

                  DRIVING ADVISEMENT SYSTEM

                  REPORT OF SCORES      VER:  11490
                                             (for IBM compatibles)

NAME:  SUPER WOMAN       DATE:  01/15/90       PAGE  1
GROUP:  40WONDER                         EXAMINER:  RG
--------------------------------------------------------------------------

** - THROUGHOUT THIS REPORT, COMPARISONS ARE BASED ON A GROUP OF OVER 60
     NON-BRAIN INJURED DRIVERS RANGING FROM 17 TO 87 YEARS OF AGE.  NONE HAD
     MORE THAN 2 ACCIDENTS IN THE PREVIOUS YEAR AND MOST WERE ACCIDENT FREE.
--------------------------------------------------------------------------

I.   SELF APPRAISAL                     W
(COMPARING CURRENT SELF TO              O
'WORST' AND 'AVERAGE' SAFE DRIVERS)     R              A
             PREDICTED                  S              V
               VALUE                    T              E
REACTION TIME:     .52   ---------------------------(X)--------

DECISION SPEED:    .59   ----------------------------(X)-------

MOVEMENT SPEED:    .16   --------------------------(X)---------

ADAPT QUICKLY:     .98   -------------------------------(X)-----

CONSISTENCY:       .31   ----------------------(X)-------------

CONCENTRATION:    .54    --------------------(X)---------------

FIELD OF VISION:  .05    --------------------------(X)---------

IMPULSE CONTROL:  2.50   ----------------------------(X)-------

DO YOU THINK YOU ARE                 +    +    +    +    +    (6)   +
CAPABLE OF DRIVING NOW?            (      NO   (---------)   YES      )

HOW DOES YOUR FAMILY FEEL            +    +    +    +    +    +    (7)
ABOUT YOUR DRIVING?                (      OPPOSED (--) SUPPORTING     )

WILL YOUR DISABILITY AFFECT          +    +    +    +   (5)   +    +
YOUR ABILITY TO DRIVE?             (      YES   (---------)   NO      )

DO YOU FEAR LOSING CONTROL           +    +    +    +   (5)   +    +
BEHIND THE WHEEL?                  (      YES   (---------)   NO      )

DO YOU EXPECT TO HAVE DIFFICULTY     +    +    +    +    +    +    (7)
(RE)LEARNING HOW TO DRIVE?         (      YES   (---------)   NO      )


NAME:  SUPER WOMAN       DATE:  01/15/90       PAGE  3
GROUP:  40WONDER                         EXAMINER:  RG

III.  REACTION TIME

    O = ACTUAL SCORE                  ) = UPPER (96%) LIMIT OF NORMS
    I = MEDIAN OF NORMS               ? = SELF ESTIMATE

MEDIAN REACTION TIME (CHOICE COMPONENT:  SIGNAL TO ONSET OF RESPONSE)
BRAKE(SIMPLE) .31   (.34  .46)   |        O  I          )
DECIDE        .47   (.59  .75)   |   O       ?          )
INHIBIT       .67   (.84  1.13)  |    O      I          )
                                 |___________I__________).............
                                          MEDIAN      LIMIT            )

MEDIAN REACTION TIME (EXECUTION COMPONENT:  ONSET TO COMPLETION OF RESPONSE)
BRAKE(SIMPLE) .13   (.15  .23)   |          O I          )
DECIDE        .13   (.15  .23)   |          O I ?        )
INHIBIT       .14   (.16  .24)   |          O I          )
                                 |___________I__________).............
                                          MEDIAN      LIMIT            )

MEDIAN REACTION TIME (COMBINED COMPONENT:  CHOICE + EXECUTION)
BRAKE(SIMPLE) .44   (.51  .66)   |      O      I?        )
DECIDE        .61   (.74  .9)    |  O          I         )
INHIBIT       .81   (1.03 1.39)  |     O     ? I         )
                                 |___________I__________).............
                                          MEDIAN      LIMIT            )

REACTION TIME VARIABILITY ('COMBINED' STANDARD DEVIATION)
BRAKE(SIMPLE) .1    (.16  .54)   |          O I   ?      )
DECIDE        .1    (.16  .46)   |         O  I          )
INHIBIT       .21   (.35  .7)    |        O   I     ?    )
                                 |___________I__________).............
                                          MEDIAN      LIMIT            )

REACTION TIME LATERALITY (RIGHT-LEFT MEDIAN)
BRAKE(SIMPLE) .02   (.02  .09)   |        (   I   :   O    )
DECIDE        .02   (.04  .12)   |        (   I   :  OI?   )
INHIBIT       .1    (.07  .25)   |        (   I   :   IO   )
                                 |........(___I___:___I____)........
                                  (     LLIM MDN  0   MDN RLIM        )


Amazin' Grace            (Neuro)Psychologist
--------------------------------------------------------------------------
(C) 1989 LIFE SCIENCE ASSOC.  : DRIVING ADVISEMENT SYSTEM (COG. REHAB. 6)
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HandiWARE - Powerful, Flexible Software Solutions for Adapted Access Augmentative Communication, and Low Vision in the MS-DOS Environment

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Introduction

The rapid advancements in computer technology benefit all mankind. This same technology applied to the needs of disabled individuals allows them to realize the full potential of these information systems - opening new avenues of communication, allowing for greater independence and increased employment opportunities. HandiWARE products were developed to provide software based solutions for disabled individuals choosing the MS-DOS environment. HandiWARE includes software packages for adapted access, augmentative communication, and low vision. Individuals facing major physical challenges given the means, have great potential to return to productive, fulfilling life. It is often not enough to be computer literate, employers demand productivity as well. HandiWARE offers physically challenged persons the opportunity to increase speed to a competitive level. As products for MS-DOS compatible computers, HandiWARE will work with nearly all standard software. The HandiWARE family includes the following products: HandiCODE, HandiKEY, HandiTALK, HandiCHAT, HandiWORD, HandiSHIFT, and HandiVIEW.

Discussion

As a basis for general discussion, all HandiWARE software has the following commonalty; compatibility with most PC's including: PC, XT, AT, AT-386, PS/2, PC/Jr, and all 100% compatibles in both 40 and 80 column mode; compatible with most popular off-the-shelf software (TSR with low memory requirements); and compatibility with most networks. Access to the PC can be achieved using one or two keys of the keyboard, single, dual, or triple switching devices. Keyboard access remains intact even when a switching device is in use. HandiWARE products that provide speech output support industry standard speech synthesizers. Integral to HandiWARE discussion is it's affordability.

Methods

For individuals with severe physical impairment two methods of alternate keyboard input are addressed with the HandiCODE and HandiKEY products. HandiCODE provides a path to personal computers by interpreting Morse code input and converting it into keyboard data. The standard Morse code assignments have been extended to include the extra keys on the PC's keyboard, plus predefined and user-defined commands. These commands are provided by a powerful macro facility. With the macro capability any series of keystrokes can be automated. HandiCODE has full speech output capabilities. PracticeCODE utility/editor, on-screen help, support of both 40 and 80 column mode, and compatibility with graphics programs are some of the many features of HandiCODE. The software provides complete flexibility in customizing the system to the individual's needs. Input speeds obtained are governed only the proficiency of the user.

HandiKEY uses a scanning matrix approach to provide an alternate means of entering keyboard strokes. Select a single character or an entire string of up to 2,000 characters through a single switch. Choose automatic scanning, manual scanning, or direct selection (using a joystick, trackball, mouse, or digitizer tablet) to "pick" the desired cell. Matrix size, location, and contents are completely definable by the user. Important features include time-saving word prediction/abbreviation expansion, speech output for computer-aided speech, and on-line cell definition. To assist individuals with limited keyboard ability HandiSHIFT provides four modes of simultaneous depression of keys. These include shift the next character and two forms of shift lock and an Apple-like shift compatibility mode.. A command line option allows disabling of the key repeat function. Additionally HandiSHIFT includes a visual on-screen beep, called See-Beep, whenever the computer audibly beeps for error, etc.

Just as HandiSHIFT addresses limited keyboard abilities, likewise HandiWORD software provides time-saving word prediction, abbreviation expansion, and keyboard macro capability. Selection is achieved using the numerics or numeric keyboard requiring a single keystroke. HandiWORD statistically weights word usage and moves the more frequently used words to the front of the selection list. Words/abbreviation expansions can be added and deleted as needed and "application specific" dictionaries can be created. The keyboard macro utility allows loading of programs, etc. In addition, HandiWORD provides translation of English to/from Spanish, German, Italian, and French. Complete program operation of HandiWORD and dictionary maintenance is available in English and French. HandiWORD supports both 40 and 80 column mode.

HandiCHAT and HandiTALK is speech-only software to augment communication for individuals requiring computer aided speech. HandiCHAT is a versatile pop-up utility which allows quick entry of text for output to an external synthesizer while running other application programs. Two modes of speech output are provided. The first mode uses a pop-up window of six (6) or twenty (20) lines where text may be entered to be spoken. The second mode provides a powerful screen-reading capability.

A single command will speak the word at the cursor, speak the sentence, speak from the beginning of the line to the cursor, or output all screen text to the speech synthesizer. HandiCHAT supports both 40 and 80 column mode.

HandiTALK allows creation of speech matrices accessed using manual scan, automatic scan or direct selection via the desired switching device. The user has complete control to modify or create matrices of up to 13 cells across by 19 rows down. A single cell can contain up to 2,000 characters.

For low vision PC users HandiVIEW magnifies an area of the screen approximately 8x (10 characters/line). HandiVIEW is unique in that it allows a "true-color" mode of magnification (non-graphic applications only) where the enlarged area appears in identical colors as the target area. A font editor is included for customized enlargement or for foreign language characters. Horizontal or vertical format magnification modes with 1, 2, 3, 4, 5 or 6 lines of magnaviewed text may be chosen. HandiVIEW is accessed via a "hot" key sequence from the keyboard (normally ALT-Space). The cursor keys move the magnaview area.

Results

Many hardware based solutions have been developed in the past decade. While these fulfilled the needs of many, their costs were beyond the reach of most users. Today's personal computers allow an alternative - powerful, yet inexpensive software solutions. HandiWARE software has provided successful assistance to individuals with ALS, cerebral palsy, spinal cord injury, neurofibromatosis with severe spastic quadriparesis, and other neurogenic diseases. Depending upon the individuals' capabilities/needs, a single HandiWARE product was chosen to meet access and augmentative communication requirements or in some cases, the combination of two separate HandiWARE products has given powerful PC access. In all cases, some working knowledge of the PC by the assessment team or by the end-user was key to most successful use of HandiWARE's extensive functionality. In conclusion, HandiWARE was designed to gainfully employ the PC's power for complete solutions to adapted access, augmentative communication, and low vision requirements.

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A Software Package for the Fault Tolerance Analysis Of Electric Wheelchair Systems

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Abstract

The use of software tools can automate the design process of electric wheelchair systems. This paper describes a software tool that focuses on fault tolerance design issues. Notable features of this tool are its ease of use, its ability to model electrical, mechanical and electro-mechanical components, its ability to generate a comprehensive, unifying, single fault tolerance model of the system, and its ability to display fault tolerance measures in a meaningful fashion.

Introduction

The application of fault tolerance concepts to electric wheelchair design can significantly benefit the wheelchair user in terms of reliability, safety, and availability. However, design is an iterative process that constantly forces the designer to determine which design is best. Iteration by its very nature is time consuming, but through the use of software tools the decision process can be accelerated.

This paper describes a software package designed to address fault tolerance design issues. With this package, measures of reliability, safety, and availability of a wheelchair system and its subcomponents can be determined, allowing the user to evaluate different fault tolerance designs and determine which one is best. Of significant note is the package's ability to provide fault tolerance analysis of the entire system under a single model. The package can account for electrical, mechanical and electro-mechanical components with respect to failure rate over time.[2] The package was written in C and has been tailored for the personal computer (MS-DOS) environment.

Program Structure

For the purpose of fault tolerance analysis, *structural decomposition* is used to reduce computational complexity. Structural decomposition is a hierarchial breakdown of the system into stages and substages.[1] The underlying assumption in creating this model is that each substage is independent of each other in their failure and fault recovery mechanisms. This allows one to independently calculate a fault tolerance measure for each substage. Once this task is complete, a fault tolerance measure for the entire system can be calculated as if each of the substages were in series.

The software package automates structural decomposition of the system by having the user enter one of five *modules* in which the user will be queried for choices relevant to that module. These modules are categorized as: 1) the system component navigation module, 2) the system component definition module, 3) the system component modeling modules, 4) the system component plotting modules, and 5) the system performance measurement evaluation modules. To illustrate the relationships between these modules we refer to figure 1.

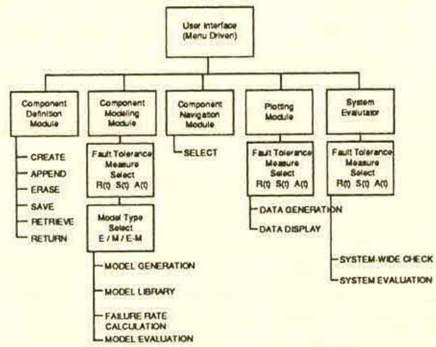

Figure 1. Structural Decomposition Block Diagram.

To provide ease of use, a menu driven user interface is used throughout the software package.[3] A main menu is used to link each module. Consequently in order to traverse from one module to another the user must pass through the main module. A fundamental concept to the package is the notion of a *current* stage. In order to structurally decompose a system, one must break the system down into many stages. The current stage is simply the stage of interest to the user.

The system component definition module allows the user to heirarchially define the system. After selecting DEFINE from the main menu, yet another menu is presented giving the user the option of appending a peer stage to the current stage, creating a first substage of the current stage, erasing the current stage, saving the defined stages, retrieving defined stages, or returning to the main menu. The underlying idea to this module is to define the system with respect to the current stage in use.

The system component navigation module allows the user to select the current stage in the framework by moving from stage to stage using the arrow keys on the keyboard. A text window is diplayed to the user indicating the current stage and is updated with every move.

Once a stage has been defined, it can be modeled. Returning to the main menu, the selection MODEL would take us into the system component modeling module. At that point a query is made as to whether a reliability, safety, or availability measurement is desired for the current stage. Once decided, another query is made as to whether or not the stage is electrical, mechanical or electromechanical in nature. If the component is electrical, another menu appears where the user may select one of a series of predefined fault tolerance models or a user-specified Markov model from a model library. If the component is mechanical, the user is then guided through a series of commercial finite element analysis packages to yield parameters α and β for a Weibull distributed failure rate. Parameters associated with the fault tolerance model selected are then queried. After entering the parameters, the program will then ask for a time value to calculate the performance measure of interest with respect to that time, for example reliability, safety or availability. The routines for yielding the parameters α and β have been written, however at the present time of this writing the routines have not been integrated into the package. Research still continues on modeling electro-mechanical components and modeling dependencies between stages.

Once the stage is modeled its behavior can be plotted. From the main menu, the selection PLOT takes the user into the system component plotting module. Upon entry into this module the user is asked to select a fault tolerance measurement (reliability, availability, safety). Then the user will be asked to either generate points for the plot or to display previously generated points. Once the points have been generated, the user then has the ability to see multiple plots for comparisons of different designs and determine time intervals of interest for the plots. From this module, qualitative evaluations of different designs over time can be determined. Points which are generated by the package are stored in a two-column format text file for easy transfer into more sophisticated data-analysis packages.

After all the stages have been modeled, the user can evaluate a total system fault tolerance measurement. Again a menu is presented offering a reliability, safety, or availability measurement. Once selected, a scan of the system is made to see if any stage has not been modeled. If so, then further computation is halted and the program warns the user. If not, then a system evaluation is perfomed on the model and displayed to the user.

Project Status

The task of adapting the original UNIX based package to a personal computer environment is almost complete. Work done to date are resolutions to user interface design issues, a Markov model engine for dependability modeling calculations, and routines for the creation and manipulation of the single system model. Further work is needed on graphical analysis tools, integration of mechanical component analysis modules, and studies into the dependability modeling of electro-mechanical components.

Conclusions

The system described in this paper is a highly-interactive software package to support analysis during the design and evaluation of electric wheelchairs. The package has been ported to a personal computer (MS-DOS) environment. Future efforts will focus on further refining the software and performing extensive evaluations of new and existing electric wheelchair designs.

Acknowledgements

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HyperCard Databases for Computer-Related Product Information

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Introduction

Clinicians who perform computer access evaluations usually have several resources available to find information about adaptive hardware and software that their clients need to operate computer systems. They may find such information by searching through personal files or by using electronic databases such as Hyper-ABLEDATA, a version of the ABLEDATA database of assistive devices developed for use on microcomputers by the TRACE R&D Center in conjuction with the Adaptive Equipment Center at Newington Children's Hospital (1,2). Often, however, a clinician must also determine the computer, peripheral devices, and software that can best aid the client in performing specific tasks, such as word processing, graphics, etc. Clinicians often search computer magazines for information about products that their clients may need, a time-consuming task. To save time, they may choose to search on-line databases for information; however, these databases often require practice to fully master their operation and can be quite expensive to use.

A set of databases in the form of HyperCard stacks on the Apple Macintosh has been developed which contain product announcements, reviews, product comparisons, and informational articles about Macintosh and IBM-compatible computers, peripheral devices, and software. The stacks have been designed for use by persons who need to quickly and inexpensively find information about computer-related products for themselves or for clients.

Methods

HyperCard on the Apple Macintosh was selected as the platform for development because HyperCard is an inexpensive but powerful application development environment which lends itself to the development of user-friendly database applications, or stacks. Users browse through the records and search for specific product information by pointing at and clicking on "buttons" using a mouse.

Using HyperCard, four stacks were developed to provide information for program staff about Macintosh and IBM-compatible computer hardware and software products. The records in the Computers-89 stack were taken from the 1989 issues of *Byte, InfoWorld, MacWorld, MacUser, PC Magazine,* and *PC World* magazines. These magazines were selected for use because of their recognition among microcomputer users for providing unbiased reviews of computer products. Every review (either short or comprehensive), product comparison, and informational article in these magazines was included in the Computers-89 stack. In addition, any announcement about a product that the stack's author thought could be useful to the program's staff or clients was also included. The records in the PC Magazine-88, PC Magazine-87, and PC Magazine-86 stacks (all of which deal almost exclusively with IBM PC-compatible computers) were taken from databases containing information from the 1988, 1987, and 1986 issues of *PC Magazine*, which were downloaded from the *PC Magazine* PCMagNet on-line service (also available to subscribers of the CompuServe on-line service). The records were then imported into HyperCard stacks modelled closely after the Computers-89 stack.

Information given in each record, or card, of the Computers-89 stack include a one-line summary of the article's contents, a key word describing the type of article (review, product comparison, etc.), the magazine in which the article appeared, the date of the issue, the page number of the article, a price (if applicable), a short description of the contents of the article, and other key words which can be used to help find the article. (See Figure 1 for a sample record.) A summary of the article title is provided instead of the actual article title because authors sometimes choose whimsical names for their articles. For example, an article titled "Getting It on Tape" in the December 1989 issue of *MacUser* was re-titled "30 tape backup drives for the Mac" in the Computers-89 stack. Information provided in each of the PC Magazine stacks is similar to that in the Computers-89 stack, but varies slightly in each stack because the *PC Magazine* editors alter the format of their databases every year.

Each of the stacks are completely menu-driven, except for the search routines which require the user to type the search terms for which he or she wants to find information. Each of the stacks provide on-line help in the form of information for the user on what each of the buttons do, how to perform searches, etc. (See Figure 2). When searching for information, users have two options: allowing the stack to find all records containing their search terms, automatically placing brief descriptions in a list that the user can later browse; or, searching for one record at a time. Figure 3 shows the first 16 records found that match the search terms "Mac" and "spreadsheet." Note that the user can either select "Browse all" to view all the records found in the search, or he or she can click on the line containing the desired record to view only the contents of that record.

Results

The set of stacks described in this paper contain a total of almost 6000 records, with almost 2300 records appearing in Computers-89 alone. The stacks allow the staff members to find in seconds information that formerly took many minutes to acquire through searching computer magazines by hand. The stacks have been used many times by the staff to find information about computers, peripheral devices, and software for use within our clinical service program and for clients. The stacks have been found to be very easy both to learn to operate and to use.

Discussion

It is anticipated that a version of HyperCard for use on IBM PC-compatible computers will become commercially available during 1990; if so, the stacks will be ported over for use by IBM PC-compatible computers. The implementation of the four stacks has been so useful that the author plans to continue entering information from the 1990 issues of *Byte*, *InfoWorld*, *MacWorld*, *MacUser*, *PC Magazine*, and *PC World* magazines. The stacks will be made readily available to all interested clinicians.

Acknowledgments

Many thanks to the creators of Hyper-ABLEDATA for their inspiration. This work was funded in part by the Crippled Childrens' Hospital Foundation of Memphis, Tennessee.

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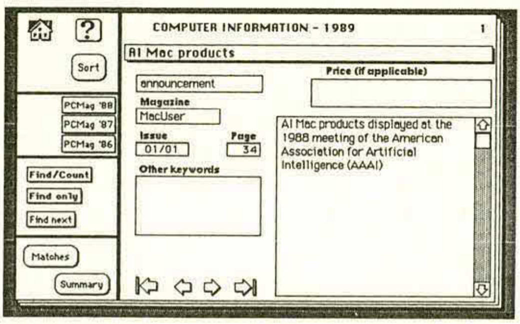

Figure 1. Example record from the Computers-89 Stack

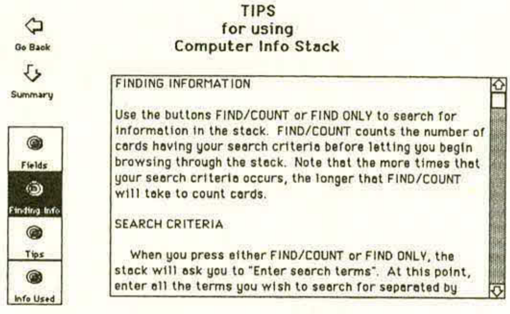

Figure 2. A sample card from the Help section of the Computers-89 stack

Figure 3. Example list resulting from a search of the Computers-89 stack for articles pertaining to Macintosh spreadsheets. The first item on each line is the card number, the second item is the type of article, and the third item is a summary of the contents of the article. Note that "fl" = first look or brief review, "pc" = product comparison, and "rev" = review.

Effect of Practice, Laterality and Gender in Tactile Letter Recognition Employing the OPTACON 6.1

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ABSTRACT

Fifteen random sequences of the alphabet were presented at four different rates to the left or right index fingertip via an OPTACON (OPtical to TActile CONverter: a tactile reading aid for the blind) to equal groups of males and females with a right hand preference. Practice, presentation rate, and gender all yielded significant main effects. Specifically, the number of letters correctly reported decreased as presentation rate increased but increased as a function of practice. Also, females correctly identified more letters than males. The order of letters correctly identified was essentially identical for conditions of gender and laterality.

INTRODUCTION

As the tactile sense is recently being considered as the modality for sensory substitution for a broad spectrum of sensory-neurological disorders it is becoming increasingly imperative that the development of devices to present tactually patterned stimulation in lieu of lost sensory information be maximally compatible with the processing capabilities of the tactile modality(1). In our laboratory we have been examining the ability to recognize letters presented tactually via an OPTACON. The concern has been directed at understanding fundamental principles involved in such discriminations and with improving the effectiveness of tactile processing of printed materials presented via electronic aids.

METHOD

Subjects: Two hundred and forty Introductory Psychology students, 120 males and 120 females, participated in this study. All observers were right handed, had never used the OPTACON and had no impediment associated with the perception of the index fingers.

Apparatus:
An OPTACON was used to present IBM standard gothic sans serif upper-case letters randomly arranged in 15 sets of the 26 letters of the alphabet. A custom designed apparatus system was used to provide computer controlled rates of presentation beneath the OPTACON camera. Letters stimulated the central 20 rows of the OPTACON tactile array. The intensity level was set at a comfortable level and white noise was presented binaurally to mask sounds emitted by the tactile array.

Procedure:
Letters were presented at rates of: 2, 4, 6, and 8 mm/sec to the left and right index fingertips. Fifteen males and 15 females were randomly assigned to one of the presentation rates and laterality conditions. A scan mode of presentation was used in which the letters were moved across the tactile array from right to left. At the beginning of each session, observers were asked to place either their left or right index fingertip on the tactile array. On each trial, the observer was presented with one of the 26 letters, attempted to identify it and was given feedback. A self pacing procedure was used.

RESULTS

The observers report of each tactile pattern, i.e., letter, was recorded. The number of letters correctly recognized were combined to provide 5 sets in which the first set represented the mean number of correct reports for the first 3 presentations of the alphabet and the 5th set was the equivalent score for the 13, 14, and 15 alphabet presentations.

Gender proved to be a significant main effect ($F = 11.73$, d.f. = 1,224, $p < .001$) with females correctly identifying approximately 20% more letters than males. Not surprisingly, both rate and practice also reliably affected accuracy of letter reports ($F = 6.88$, d.f. = 1,224, $p < .001$; $F = 93.07$, d.f. = 4.896, $p < .001$). Generally, the number of letters correctly reported decreased as rate of letter presentations increased but increased as a function of practice. The only significant interaction was between rate and set or practice ($F = 2.81$, d.f. = 12.896, $p < .001$). Figure 1 illustrates both the significant gender and practice main effects. In Figure 2, the significant effect of rate as well as its interaction with practice or set are apparent.

Spearman's rank order correlation coefficients were calculated using the values of the matrix diagonals (correct reports of letters presented) for both laterality and gender. Values of rho for these two conditions were .934 and .953. Thus the order of letters identified according to report accuracy were essentially identical for males and females as well as for the left and right hands.

DISCUSSION

The major findings of this study were that although inexperienced male and female

OPTACON users significantly improved in their ability to correctly recognize letters presented tactually to the pads of either their right or left index fingertip, females were reliably more accurate than males. The obtained gender difference across laterality conditions is somewhat at variance with previous findings. However, some suggest reports of sex differences in laterality studies are not uniformly interpretable(2). The trend of gender and laterality X practice interaction, in which for females right hand performance was superior to the left hand while for males left hand performance was better than for the right hand hints at least at some interesting speculation.

Presentation rate effects are important in order to specify the threshold processing rate at which individual letters and sequences of letters or words can be identified with the greatest accuracy. Based on the present study rates of 2 and 4 mm/sec lead to near equivalent levels of report accuracy while an increase to 6 mm/sec lead to an appreciable decline in the number of letters accurately reported.

In addition to the specific findings in this study, a transcending and more fundamental issue in this area of research has to do with tactile spatio - temporal pattern perception. Ultimately tactile recognition of 2 dimensional patterns is limited by cutaneous spatial resolution. Such a consideration raises the issue of perceptual integration in tactile pattern recognition. It seems likely that as subjects learn to integrate successively received sensory information with practice, their performance becomes increasingly limited by the more sensory mechanisms involved in spatial resolution of touch.

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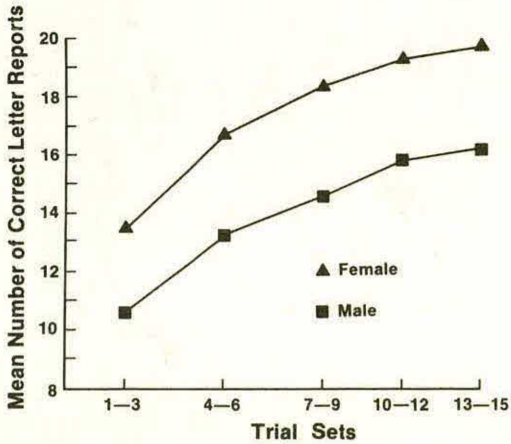

Figure 1

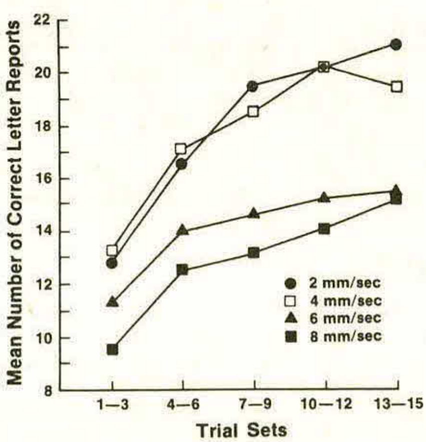

Figure 2

MOBILITY MEASUREMENT: A COMPUTER-ASSISTED APPROACH

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INTRODUCTION

To successfully evaluate the orientation and mobility of visually impaired persons, the behaviors associated with orientation and mobility must be reliably measured. Such a measurement system should include two different aspects of these behaviors: the effects of being oriented and of being mobile. Other systems of measuring mobility have been either labor intensive (Shingledecker, 1978) or do not provide a means for annotating the mobility behaviors at the time/place they occurred(Brabyn, Sirisena, and Clark, 1978).

In an ongoing series of studies on spatial orientation of visually impaired persons, we have assessed several measures of spatial knowledge. To relate those measures to specific mobility behaviors, we had to be able to record the mobility behaviors of persons while they were acquiring information about an environment that was new to them. The purpose of this paper is to describe the method of measuring mobility that we developed.

METHODS

We developed a means for recording the subject's movements using an on-line tracking of the visually impaired traveler via a cursor and a digitizing pad. The kinds of encounters the traveler had with environmental objects were also recorded in real-time. A menu-driven QuickBASIC computer program was written by one of the authors (KRS) with input and feedback from the other authors. The hardware on which this program runs consists of an IBM PC/XT (with one floppy drive, one 10Mb hard disk, a color monitor with graphics screen, a standard keyboard, serial port, parallel printer and 512k RAM) and a Summagraphics digitizing pad (Model number MM1201) with a three button cursor. The Summagraphics digitizing pad reports absolute rather than relative XY coordinates.

Upon execution of the compiled program, a menu is shown that permits the user to 1) record a new trial, 2) analyze a previously recorded trial, 3) recreate a screen from a previous trial, 4) view a list of data files, or 5) quit the program. If the choice is to record a new trial, the program clears the screen and draws a map of the room. The user places the digitizer cursor at the starting point on the screen. When the subject begins to walk, the experimenter pushes the first of the three cursor buttons, which places a marker at the start point and begins to record the time and coordinates of the cursor movements. The experimenter follows the subject's movements through space with the cursor and a trail of dots on the screen map shows the progress of the subject. The data collection continues until one of the other two buttons is pushed.

The second button is used to mark an intermediate point (such as arriving at an object in the room that is a subgoal) and causes a pause in the data collection. The timer halts at this point and is only restarted when the experimenter presses the second button again, indicating that the new subgoal has been presented to the subject. The third button is used to mark the end point of the trial and to end data collection. Data coordinates and times are recorded in the raw data file whenever a movement of at least 6" in real world distance has been made. Thus, when a subject pauses there is no recording of coordinates as such data would be redundant. However, time is still being accumulated.

In addition to recording coordinates over time, the program allows the experimenter to record up to ten categories of mobility behavior (e.g., hand or cane contacts with objects and pauses in movements). These behaviors are entered through the numeric keypad of the computer. The category is entered into the data record in real-time. Also, the program records the name of the nearest object in the room at each coordinate data entry. Thus at the end of a trial the data consists of a series of records that include XY coordinates, time, speed, nearest object and any behavior markers that may have been entered. These data are stored in a binary file that can be used later to recreate the trial or used in data analyses. The elapsed time on route, file name, nearest object, and last mobility behavior category chosen are displayed on the side of the map screen.

The analysis option from the program menu allows the user to have a summary report of the trial on the screen. This report contains the elapsed time between subgoals, the distance traveled between subgoals and total time and distance over the trial. If there are behavior markers between goals the same information is shown for each of those markers. All of this data is written to an ASCII file and stored for later inspection and use.

The recreation option on the menu permits the user to select a data file and then redraw on the screen the path taken by the subject. This screen can be printed on an appropriate printer using the screen dump capacity of the computer. On the screen recreation the user can have the route recreated without any pauses or it can be done with a pause after every marker and subgoal. The recreation marks all behavior markers with a "+" sign and all subgoals with a "X" mark. The path taken by the subject is shown with "." for each data point recorded.

The program is designed to be user friendly in that it is menu driven. Training in the use of the cursor to follow the movements of the subjects required approximately five hours of practice prior to starting the study. Reliability studies indicate a high level of agreement between the user/program's measures of subject movement and a second source who measured the time intervals independently.

RESULTS AND DISCUSSION

The computer-assisted mobility measurement system we have developed is an improvement over previously described systems because not only does it provide a map of the movements of the person, it also annotates the map with specifics of mobility behaviors that occur at particular points in the environment. Thus the person's behaviors can be related to other aspects of learning such as spatial orientation. The system is also less labor intensive for the amount of information gained. With minor modifications in the program, the particular categories of behavior can be modified. This permits the program to be used for studies in other fields, such as user behavior patterns in open or public areas.

ACKNOWLEDGMENTS

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Sample from data file created during recording of a trial

Pt. #	Time (in secs)	X coor.	Y coor.	Marker	Option
1	0.00	25	321	A	-
2	0.22	25	321	A	-
3	2.42	25	316	A	-
...					
26	10.41	40	154	A	OutlnC
27	14.20	40	154	A	OutlnH

Sample from data file created with "Analyze" option

Mrk/Opt	TotET	Time(s)	Distance (ft)	Speed (f/s)	Nearest Object
UnanticC	0:08.7	0:08.7	14'2"	1.62	DTable
OutlineC	0:10.2	0:10.2	14'4"	1.40	DTable
OutlineH	0:14.0	0:14.0	14'4"	1.02	DTable
Reversal	0:16.5	0:16.5	17'0"	1.03	DTable
OutlineC	0:17.2	0:17.2	18'6"	1.07	DTable
1	0:25.7	0:25.7	30'9"	1.12	B
2	0:40.0	0:12.5	22'9"	1.82	C
...					
Totals:	1:40.7	1:40.7	156'2"	1.55	

METABOLIC ASSESSMENT OF A SUBJECT WITH A NEUROMUSCULAR IMPAIRMENT USING THE DOUBLY LABELED WATER TECHNIQUE

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INTRODUCTION

Indirect calorimetry has been extensively used to evaluate metabolic functioning. Few studies, however, have been conducted to evaluate the metabolic efficiency of subjects exhibiting neuromuscular impairments (5). A primary reason for this lack of research must be attributed to the inability of these subjects to tolerate traditional testing protocols which require the collection and analysis of expired air through a mouthpiece and one-way valve arrangement. These measurement techniques are cumbersome, requiring data to be collected over extended periods of time, and are often invalid in subjects with neuromuscular impairments due to poor oral-motor control (2).

The doubly labeled water ($^2H_2{}^{18}O$) method has been shown to be a valid and effective technique for measuring energy expenditure in free-living subjects over extended periods of time (3 to 14 days) (4). Since this technique does not require the collection of expired air, application of this method with subjects exhibiting neuromuscular impairments would be beneficial.

The premise of the doubly labeled water method is that after a loading dose of doubly labeled water ($^2H_2O/H^{18}O$), ^{18}O is eliminated from the body in expired CO_2 and water in the urine, while ^2H is eliminated only in the urine. Furthermore, the oxygen atoms in expired carbon dioxide are in isotopic equilibrium with oxygen atoms in body water. Measurement of the rate of disappearance of ^2H from the urine is reflective of H_2O flux, while measurement of the rate of disappearance of ^{18}O reflects H_2O and CO_2 flux. The difference between the two rates of disappearance reflects CO_2 flux. CO_2 flux can then be converted to oxygen consumption or energy expenditure.

The purpose of this preliminary study was to apply the techniques used in the doubly labeled water method to asses metabolic function in a subject with a neuromuscular impairment. Results of this work will assist in determining if this method can be effectively used to measure long term energy expenditure in this subject population.

METHODS

Subject

The subject in this case study was a non-ambulatory 31 year old male exhibiting characteristics of moderately involved spastic cerebral palsy. At the time of the study the subject was 60.9 kg, and 24% body fat.

Protocol

Following a 12 hour fast the subject drank ^2H_2O (99.8% atom%, Merck and Co., St. Louis, MO) and $H_2{}^{18}O$ (7.1 atom%, E.G. & G Mound Applied Technologies, Miamisburg, OH) in a dose of 0.13 g/kg ($H_2{}^{18}O$) and 0.15 g/kg (^2H_2O) diluted to 100 ml final volume with tap water. The subject then drank 50 ml of distilled water to rinse down any isotope remaining in his mouth. Two hours later the subject was asked to void his bladder in order to eliminate urine produced prior to equilibration of the ingested water. A three hour urine sample was collected for determination of ^2H and ^{18}O enrichment. Subsequent urine samples were collected 6.6 and 10.6 days after the initial sample. Urine samples were stored at -20 °C until analysis.

From 0 to 6.6 days the subject was minimally active and exclusively used his electric wheelchair. During days 6.6 to 10.6 days the subject participated in normal daily activities while using his manual wheel chair and swam on two occasions.

^2H_2O Analysis

The H_2O-^2H_2O mixture in the original urine sample was purified by allowing 2.5 ml of it to equilibrate with 2.5 ml of distilled H_20 in a Conway diffusion dish. The covered dishes were incubated at 37°C for 48 hrs and then cooled to room temperature. The ^2H_2O concentration in the equilibrated ^2H_2O-H_2O mixture was determined using a fixed-filter infrared analyzer (Miran model 1A, Foxboro Analytical, Foxboro, MA)by measuring the absorbance at 2500 cm^{-1} in the infrared region of the spectrum (1). $^2H_20$ concentration in parts per million (PPM) was determined by comparing the absorbance with a standard curve developed by adding known quantities of ^2H_2O to distilled water, which were extracted and measured as previously described (1).

$H_2{}^{18}O$ Analysis

5 ml of urine was equilibrated with approximately 50 ml of CO_2 at 25°C and 190 mm HG for at least 24 hours. The CO_2 was cryogenically purified under vacuum using an ethanol bath (-90 to -110 °C) to remove water and a liquid nitrogen bath (-196°C) to isolate the CO_2. ^{18}O isotope abundances were measured, in terms of atom percent excess (APE) relative to a working standard calibrated against Standard Mean Ocean Water (SMOW), on a ZG SIRA24 mass spectrometer. The methods described above are similar to those described by Schoeller et al (4).

Calculations

The molar equivalent of total body water (TBW) was calculated from the initial ^2H_2O concentration using the following equation: TBW = Grams of ^2H_2O administered/ ^2H_2O concentration at Day 0(3).

The ^2H and ^{18}O isotope elimination rates were determined, for both time periods, by the two point method using the following equation: $k = (\ln S_f - \ln S_i)/dt$ (4). Where S is equal to the concentration of the isotope in parts per million and atom percent excess for ^2H and ^{18}O, respectively.

Mean daily CO_2 production (rCO_2) in terms of moles per day was calculated, for both periods, by using the following equation: $rCO_2 = TBW(k_O - k_H)/2.08 - 0.015Nk_H$ (4). rCO_2 was then multiplied by 22.4 L/mol to obtain the liters of CO_2 expired per day (L/day).

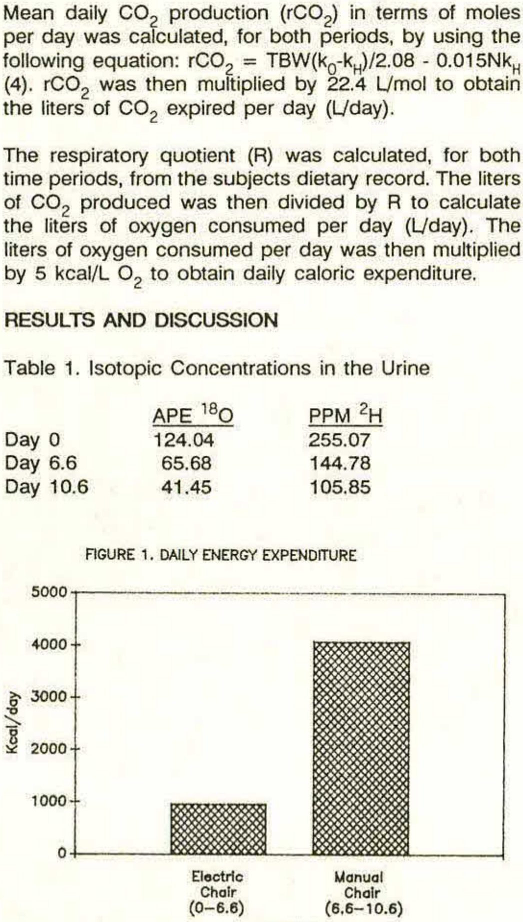
The respiratory quotient (R) was calculated, for both time periods, from the subjects dietary record. The liters of CO_2 produced was then divided by R to calculate the liters of oxygen consumed per day (L/day). The liters of oxygen consumed per day was then multiplied by 5 kcal/L O_2 to obtain daily caloric expenditure.

RESULTS AND DISCUSSION

Table 1. Isotopic Concentrations in the Urine

	APE ^{18}O	PPM ^2H
Day 0	124.04	255.07
Day 6.6	65.68	144.78
Day 10.6	41.45	105.85

FIGURE 1. DAILY ENERGY EXPENDITURE



The daily energy expenditures described in Figure 1 change accordingly with the alterations in activity level of the subject. For a normal individual the size of this subject (60.9 kg) minimal daily energy expenditure is predicted to be approximately 1400 kcal/day. Therefore, the daily energy expenditure reported during the first time period (Day 0 to 6.6), may be low. It is possible, that the resting metabolism of the subject was below the estimated basal rate due to several factors including; lower than normal lean muscle mass and an extended period of inactivity. Nevertheless, the doubly labeled water method appears to be an effective means of determining changes in energy expenditure in subjects with neuromuscular impairments and with further refinement should be able to be used reliably in a clinical setting.

This technique, designed to determine metabolic expenditure over an extended period (3-14 days) may provide a valuable method for evaluating the effectiveness of various rehabilitative strategies. For example, the efficiency of various wheelchair designs or prosthetic devices may be determined by calculating the energy expended over several days.

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PEAK CARDIOPULMONARY RESPONSES OF AMBULATORY CEREBRAL PALSIED ADULTS TO FOUR TYPES OF EXERCISE MODALITIES

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ABSTRACT

Peak cardiopulmonary fitness/work capacity of ambulatory cerebral palsied (CP) adults have been determined by arm-crank ergometry (AC) or bicycle ergometry (BE). In the present study, the Schwinn Air-ergometer (SAE) and treadmill (TM) have been evaluated and compared with the AC and BE. Eight ambulatory CP adults each performed exercise tests to volitional exhaustion, on separate days, utilizing the four modes of exercise. Peak values for heart rate and respiratory quotient were not significantly different, but higher mean values were seen for the SAE when compared to the other three modes. Significant ($p < .05$) differences were seen for peak oxygen consumption (SAE and BE >AC, SAE > TM) and peak minute ventilation (SAE and BE > TM and AC, TM > AC). The results indicate that when evaluating the cardiopulmonary fitness/work capacity of ambulatory CP adults, exercise tests using the SAE or BE are the most optimal, followed by the TM and AC.

INTRODUCTION

Properly evaluating the cardiovascular fitness/work capacity of cerebral palsied (CP) adults is of importance when considering modification of worksites to improve their range of employment. By knowing the maximal work capacity of adult CP individuals, the rehabilitative engineer would have the information necessary to base task design or task redesign on a specific percentile of maximal capacity. Maximal physiological parameters may also be utilized to assist the engineer in making decisions regarding selective screening (i.e., assigning a task that fits within a specific percentile of the maximal capacity).

To date, however, only a paucity of scientific work has been directed toward developing optimal exercise protocols for properly evaluating the fitness levels of ambulatory CP adults. Arm crank ergometry (1) and bicycle leg ergometry (5,6) have been modalities most frequently used to evaluate the cardiovascular fitness of ambulatory Cerebral Palsied (CP) adults. A treadmill (TM) test has only been reported on CP children (2). Recent work has established the Schwinn Air-Dyne (SAE) ergometer as a new modality for testing the fitness levels of adult lower limb amputees (7) and mentally retarded adults (8-9), two disabled populations who also suffer from limited ambulatory capacities. The Schwinn Air-Dyne ergometer (SAE) is an air-braked ergometer that incorporates both upper (push-pull) and lower (cycling) body musculature.

Evaluation of the capabilities of the TM and SAE to measure the cardiopulmonary capacities for ambulatory CP adults has not previously been published. The purpose of this study, therefore, was twofold: 1) to determine the maximal physiological responses of ambulatory CP adults during incremental exercise using the TM and SAE; and 2) to compare these responses with arm crank ergometry (AC) and bicycle ergometry (BE).

METHODS

Subjects. Eight physically active (i.e., all employed) ambulatory CP adults (3 females and 5 males) volunteered to participate in the study. Their descriptive characteristics are shown in Table 1. The percentage of body fat was determined by the sum of seven skinfolds using the methods of Jackson and Pollack (3) for males and Jackson and coworkers (4) for females. Prior to all testing, each subject gave a written informed consent for all procedures. This research was approved by the Institutional Review Board for human subjects of Wichita State University.

Testing Protocols. The TM test consisted of subjects walking at a predetermined speed at 0% grade for two minutes, with incremental increases in grade of 2.5% every two minutes. Speed was determine prior to the test during a practice session. The speed chosen was the fastest speed that the subject could safely walk. Speeds ranged from .6 to 1.5 mph. Subjects were allowed to hold on to a handrail for balance.

The SAE is an air-braked ergometer and utilizes air resistance on wind vanes set perpendicular on the flywheel to provide workloads ranging from approximately 25W to 500W and at pedaling rpms ranging from 29 to 72 rpms, respectively. The SAE differs from bicycle ergometry in that work level for the SAE is raised by increasing pedaling rate rather than pedaling at a constant rate while increasing resistance to pedalling. The exercise test on the SAE consisted of exercising at an initial work load of approximately 25W (29 rpms) for two minutes and increasing the workload approximately 25W (and average of 4 rpms) every two minutes.

TABLE 1: SUBJECT CHARACTERISTICS*

	Age (yrs)	Weight (kg)	Height (cm)	Body Fat (%)
Males (n=5)	29+3	77+14	171+14	22+6
Females (n=3)	34+10	65+11	153+3	31+9
Overall (n=8)	32+6	73+14	165+14	25+8

* Mean + SD

Arm cranking on the Monark AC was performed with subjects seated facing a table on which the Monark AC was attached. The table's height was adjusted so that the pedal shafts, when horizontal, were level with the subject's acromioclavicular joint. The exercise test on the ACE consisted of exercising at 5W for two minutes with incremental increases of 5W every two minutes. Arm crank rate was 50 rpm. Two males, because their arm and shoulder musculature were less affected by the disease, exercised initially at 10W with incremental increases of 10W. For one female, initial exercise level was approximately 2W with incremental approximate increases of 2W every two minutes.

The Schwinn Bio-Dyne was used for the BE test. The BE test consisted of exercising at an initial work load of 25W for two minutes with incremental increases of 25W every two minutes. Subjects were asked to pedal at a rate of 60 rpm.

On a day separate from the testing days, each subject practiced on all four modes of exercise. The subjects were randomly assigned to complete one of four tests on four different days over a 2-week period. For all four tests, subjects were exercised until volitional exhaustion. Volitional exhaustion was defined as the work level at which the subjects felt they could no longer continue. For the SAE and BE tests, five subjects had their feet strapped to the pedals in order to perform the tests.

Physiologic Variables. Throughout all four modes of exercise, subjects expired air was monitored by a metabolic measuring cart (SensorMedics 4400) which determined Oxygen uptake (VO2 ml/kg/min), pulmonary ventilation (VE L/min), carbon dioxide production (VCO2 ml/kg/min). An ECG (leads I, II, III, AVR, AVL, V1, V2, V5) was monitored throughout the first test to detect dysrhythmia. For all four exercise tests, heart rates were monitored continuously by telemetry (UNIQtm Heartwatch) and recorded every 30 seconds. Blood pressure was measured before exercise, during the last minute of each exercise level, and after exercise until it returned to resting levels. For three subjects who needed their arms for stability during the BE and SAE tests, exercise was stopped following each exercise level and blood pressure was immediately measured. The same procedure was used for all subjects during AC testing.

Statistical Analysis. Means (x) and standard deviations (SD) were calculated for all variables. Peak VO2 ml/min/kg, peak HR, peak VE L/min, and peak respiratory quotient (RQ) for all eight subjects were analyzed by repeated measures one-way ANOVA, followed by a Tukey multiple comparison to detect specific differences ($p < .05$).

RESULTS

The physiological responses (x + SE) at peak exertion for the four modes of exercise are shown in Table 2. Peak HR and RQ were not

TABLE 2: PEAK PHYSIOLOGICAL RESPONSES FOR THE FOUR MODES OF EXERCISE *

	SAE	TM	BE	AC
Peak HR (b/min)	174 + 18	159 + 25	169 + 23	144 + 27 @
Peak VO2 (ml/kg/min)	26 + 6	21 + 7	24 + 6	17 + 6 !
Peak VE (L/min)	77 + 23	55 + 18	72 + 23	45 + 22 #
Peak RQ (VCO2/VO2)	1.12 + .1	1.03 + .1	1.11 + .12	1.09 + .09 @

* Mean + SD

@ No significant difference between means.

! Both SAE and BE significantly higher than AC, AE significantly higher than TM, no significant differences between SAE and BE, and no significant difference between TM and AC.

Both SAE and BE significantly higher than TM and AC, TM significantly higher than AC, and no significant difference betweens SAE and BE.

SAE = Schwinn Air-Dyne ergometer, TM = treadmill, BE = bicycle ergometry, and AC = arm crank ergometry

significantly different for all four modes of exercise. For peak VO2 (ml/kg/min), the SAE was significantly higher than TM and AC, whereas BE was significantly higher than AC. No significant difference was shown between SAE and BE, BE and TM, and TM and AC. For peak VE (L/min), both the SAE and BE were higher than the TM and AC, the TM was significantly higher than the AC, and no significant difference was seen between the SAE and BE.

DISCUSSION

This study was designed to determine the peak physiologic responses of ambulatory CP adults during incremental exercise using the SAE and TM and to compare these responses to those of two previously reported methods, the AC and BE. While peak HR and RQ were similar among the four modes of exercise, significant differences were seen for peak VO2 (SAE and BE > AC, SAE > TM) and peak VE (SAE and BE > TM and AC, TM > AC). Although not significant, both the SAE and BE did show higher peak HR and RQ than both the TM and AC. The results of this study highlights the importance of selecting the proper mode of exercise when evaluating the cardiopulmonary capacities of ambulatory CP adults.

CONCLUSION

Although the small number of subjects in this study warrants further evaluation, the results of this study strongly suggest that when evaluating the cardiopulmonary fitness/work capacities of ambulatory CP adults for task design/redesign or selective screening, exercise tests using the SAE or BE are the most optimal, followed by TM and AC.

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AGONIST-ANTAGONIST MUSCLE CO-CONTRACTION: UBIQUITOUS BUT UNAPPRECIATED

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Introduction

Since an individual muscle can only pull, the mammalian motor system is replete with arrays of muscles across joints in order to produce bidirectional flexion or extension, abduction or adduction, etc. Opposing pairs of such muscles are called agonist and antagonist--for example, the tibial anterior and soleus about the ankle, or the biceps and triceps about the elbow. The lowest level of activation of an agonist-antagonist pair would have one muscle inactivated with the other producing a force to generate a torque or moment about the joint to cause rotation of body segments proximal and distal to the joint. But the agonist and antagonist muscle can be concurrently innervated, a condition called co-activation, or co-contraction. With both muscles producing force, only the difference between their forces--the net force--produces joint torque. With co-contraction, the force experienced at the joint is the sum of the antagonist and agonist muscle forces. Equal force contributions from each muscle would yield no torque and no motion.

Since any muscular contraction is metabolically costly, frequently employed patterns of muscular activity, such as level walking, presumably reflect an evolutionary drive towards minimizing energy consumption. Thus any co-contraction in the opposing muscles appears energy-wasteful. Another argument against co-contraction arises from meuromuscular anatomy. The spindles in an innervated contracting muscle return reciprocal inhibition to the lower motor neuron pool of the antagonist muscle. Thus in the absence of other central nervous eystem drive, co-contraction would be inhibited.

As early as the University of California at Berkeley studies of the 1940s and since, electromyographic data on lower-extremity muscle activity during walking have exhibited agonist/antagonist co-contraction about the hip, knee, and ankle. Even so. virtually all contemporary gait analysis ignores the contributions of co-contraction when evaluating the torques and force experienced by a joint. This omission (or unawareness) results from the inverse Newtonian analysis employed in movement studies. Body segment translational, or angular acceleration, processed from kinematic data, multiplied by the segment inertia, yields the force or torque each segment is experiencing. Since gait analysis data are kinematic, only those muscle force contributions which produce motion are detectable--that is to say only the net difference between agonist/antagonist muscles across the joint produced the observed motion. Thus even accurate gait analysis studies establish only the lower limits of the forces experienced by the joints. Any co-contraction increment, due to balanced forces in opposing muscle, is undetectable. This oversight in gait analysis studies carries over to the use of joint force and torque data to estimate the time-varying forces in the participating muscles. Whether calculated by aggregating functionally similar muscles to permit analytical solutions or by employing optimization techniques, the predicted force trajectories of individual muscles establish only the lower limits of those forces, which may be significantly incremented by co-contraction contributions.

Recent and ongoing studies in the Newman Laboratory under the auspices of the Harvard-M.I.T. Rehabilitation Engineering Center are producing direct experimental evidence of the presence and effects of co-contraction and explaining why the neuromuscular system adopts such a metabolically costly strategy.

Data from an Instrumented Hip Endorposthesis

A study quantifying the mechanical environment experienced by cartilage in the human synovial joint *in vivo* has provided experimental evidence of the timing and magnitude of co-contraction contributions. A spherical femoral head replacement prosthesis bears against natural acetabular cartilage. Fourteen localized areas sense pressure and telemeter these data at a rate of 253 frames per second. Direct evidence of hip muscle co-contraction prior to heel strike in level walking is demonstrated by comparing pressure data from the highest reading transducer versus the time-synchronized foot-floor vertical force. The pressure rises in the hip socket before the heel strikes the force plate.

The range of co-contractile contributions depends on the movement. During the stance phase of level walking, the highest reading transducer in the superior region of the acetabulum typically registered a maximum 5 MPa. The highest recorded magnitude, 18 MPa directed posteriorly, occurred while rising from a chair. While ascending stairs, the highest magnitude, typically 10 MPa, was directed in between walking and rising. That these significantly higher magnitudes of pressure in the latter two movements arise from co-contraction is clear from myoelectric recordings of the temporal activity in the agonist/antagonist muscle groups across the joint.

These pressure readings and associated EMG records, while indicating very significant co-contraction activity, are not quantitative measures of the force the joint experiences due to co-contraction. The need for high confidence, direct experimental measurements of joint force becomes evident upon review of kinematic data-based inverse Newtonian estimates of hip force in the literature, which for level walking range from one to eight times body weight. Attempts thus far elsewhere to measure this force experimentally have failed shortly after implantation with data of uncertain quality. Accordingly, we have designed a hip force and moment transducer for incorporation into our pressure-sensing transducer, utilizing the demonstrably successful external powering and telemetry system.

Co-Contraction as a Means of Joint Impedance Control

Why the neuromuscular system would resort to metabolically costly co-contraction becomes clear when one considers the dynamics of a task, such as rising from a chair. Stability requirements during the relatively slow rising motion, and the need to transfer momentum from trunk movement to body erection, both require "stiffening" or increasing the impedance at the hip joint, a direct consequence of co-contraction.

Related research in the Newman Laboratory supervised by Professor Neville Hogan has studied impedance control as a means of enhancing an amputee's natural control of a myoelectrically implemented elbow prosthesis. Other research by Dr. Hogan demonstrates that primates perform pointing tasks by employing co-contraction, even following dorsal root denervation.

Conclusions

Co-contraction is much more prevalent in the activities of daily living than heretofore reported. In particular, the forces on joints estimated from gait analysis studies underestimate the forces actually experienced. More confident quantification of the joint force during many normal activities is essential for the safe specification of joint-replacement prostheses, for understanding joint deterioration in osteoarthritis, and for understanding the contribution of individual muscles to movement.

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COMPUTER CONTROL OF A WHEELCHAIR DYNAMOMETER

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Abstract

This paper presents the development of a computer controlled wheelchair dynamometer that is able to simulate road/track conditions for a wheelchair race through the use of a PID controller and mathematical models. This simulator can be used to record and analyze the torque, speed, and power generated by a wheelchair rider.

Introduction

We wished to evaluate new assistive device technology especially in the area of wheeled mobility. Several dynamometers have been developed in the past (5) and our intention was to develop a computer-controlled wheelchair dynamometer that could simulate actual road conditions. The wheelchair dynamometer we used has been previously described (2).

Methods

The wheelchair dynamometer and its various components, presented in block diagram (Figure 1), can be modeled mathematically (1). Using these math models we were able to derive equations that define the torque, speed, and power which depend on these models and the description of the course (road conditions).

The equation we used to characterize the torque produced by the roller is:

$$T = (I + I_R(R/r))\,\dot{\omega} + C\,\omega^2 + M_B\,\omega + W_R b_R + T(\omega,\theta,t)$$

in which the first term describes the contribution due to the inertia of the rear wheel and the roller, the second term represents the air resistance, the third term the effect of bearing friction, and the fourth the rolling resistance (1).

The inclusion of the last term is required to simulate road/track conditions and is expressed as:

$$T(\omega,\theta,t) = C_2\omega^2 + C_3\omega + C_4\cos\theta(x) + C_5 + K_5\sin\theta(x)$$

where $\theta(x)$ is an external function that describes the course (1).

We used a PID controller (4) for this investigation. With this controller and the mathematical models for the dynamometer components we derived equations to calculate the desired torque, speed, or power for five different types of control:
(1) Open-loop-torque control which simulates the torque acting upon the wheels due to the changing slope of the road surface.
(2) Open-loop-power control which simulates the propulsion of a wheelchair acting against a constant power.
(3) Closed-loop-speed control in which the controller encourages the subject to maintain the

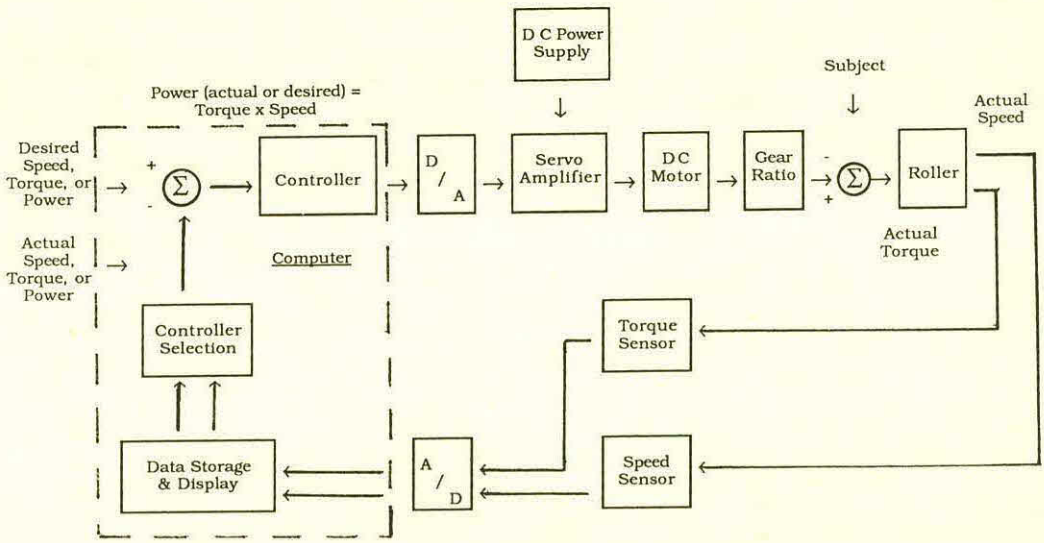

Figure 1. Block Diagram for Half of an Independent Rear Wheel Wheelchair Dynamometer with Controller and Display

desired speed by increasing or decreasing the mechanical resistance.
(4) Closed-loop-torque control in which the controller encourages the subject to maintain the desired torque by increasing or decreasing the mechanical resistance.
(5) Closed-loop-power control in which the controller encourages the subject to maintain the desired power by increasing or decreasing the mechanical resistance.

The complete computer program (see Figure 2) includes the ability to enter some chosen road or track course which is used in the calculation of the torque contribution due to road conditions. We are also able to display and save the raw data as it is acquired by the analog-to-digital converter. The ability to save this data is especially important since it allows more detailed analysis later. We used the library functions provided by National Instruments' LabWindows Software (3) to perform the data acquisition and graphing functions.

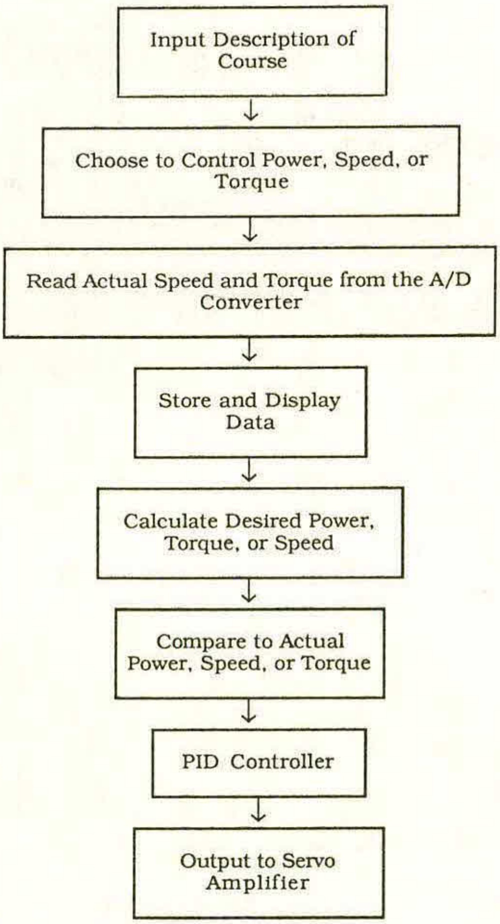

Figure 2. Flow Chart for the Computer Program that Controls the Wheelchair Dynamometer.

We wanted the resolution of the information we acquire to be small enough so that we are able recognize changes in the parameters being measured, therefore we set the sampling rate at 100 samples per second. This value can be changed as required.

Using the PID controller and the various mathematical models the desired torque (speed, power) can be determined and compared to the actual corresponding torque (speed, power), which causes the computer to change the output of the digital-to-analog converter to adjust the voltage entering the motors of the dynamometer, which in turn produces a change in the roller torque that can either hinder or aid the forward motion of the rear wheels of the wheelchair. The use of armature controlled D.C. motor/generators allows us to continuously produce torques over the full range of the motor/generator capabilities.

Discussion

This wheelchair dynamometer can simulate undulations and road-crown in a laboratory setting. This will allow us to better develop wheeled mobility devices from a human-machine design perspective. The dynamometer can also be used to study the physiology and dynamics of wheeled mobility.

Acknowledgements

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A QUICK RELEASE TILT IN SPACE FOR A LIGHTWEIGHT WHEELCHAIR

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ABSTRACT

With consideration to commercially available solutions for a tilt in space, a custom system has been developed for lightweight wheelchairs. This quick release tilt in space mechanism is designed for easy storage and operation with emphasis on safety. Such a prototype has been effective in the evaluation of a 5 year old boy with cerebral palsy. Future development aims to make this mechanism suitable for a variety of lightweight frames.

INTRODUCTION

As studies have shown, variable tilt in space, either attendant or client controlled can shift a client's weight bearing areas, effect respiratory compromise by encouraging postural drainage, and increased comfort. (1) Such systems have been incorporated into evaluation frames as well as manual and power wheelchair bases. Regarding mobility bases, a tilt in space mechanism is attached to the existing posts for a reclining backrest. This paper presents a design for a quick-release tilt in space attachment suitable for a lightweight wheelchair, where a reclining backrest mechanism does not already exist.

METHODS

The designer and physical therapist, along with the parent of a young child with severe cerebral palsy, discussed the advantages of a tilt in space for better positioning for her child. The family having already purchased a child's lightweight frame, the designer and therapist considered the following design parameters:

1. easy removability of tilt in space for car storage
2. maintain collapsibility of mobility base
3. maintain child's center of gravity within the wheelbase of the chair for safety and stability
4. consider potential use of this tilt in space mechanism for other manual wheelchair frames.

Tests for frame stability for specific body weights and recline angles were conducted with a profile model of the tilt in space before producing a working prototype.

SOLUTION

The working prototype for the tilt in space mechanism was constructed from 6061 T-6 and 6063 T-6 aluminum. Joined parts were tig welded. Figure 1 illustrates this mechanism. Pivot points are nylon-lined to prevent seizing. In addition, nylon rollers were used to facilitate the forward sliding motion required. An ACME screw was used to produce the linear and tilting motion. The quick release yokes were made of aluminum with two ball lock pins to release the entire system. A ball type caged thrust bearing was used to ease the work of turning the crank handle. The crank handle folds out of the way and features a spring-loaded pin lock to prevent the crank handle from unintentionally rotating. Figure 2 displays a working diagram of this prototype.

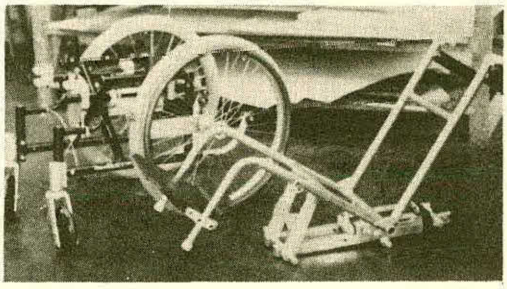

Figure 1. quick release tilt in space mechanism

RESULTS

For a full recline of the tilt in space, the crank handle requires 27 turns for a maximum 37 degree tilt. The maximum weight tested for this lightweight frame was 200 lbs. The maximum suggested weight is 150 lbs. Frame stability was maintained in this tilting range of 0 to 37 degrees. Easy and safe use of quick release pins and handle rotation, as well as overall comfort have been noted during a 1 month evaluation period.

MECHANICS OF THE TILT IN SPACE SYSTEM

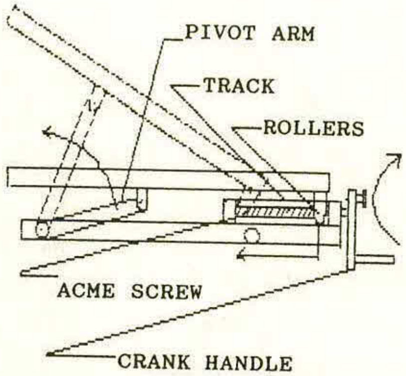

Figure 2. working diagram of tilt in space mechanism

Rotating the CRANK HANDLE CCW turns the ACME SCREW attached to the ROLLERS in the TRACK. This creates the linear motion to move the system forward. With the linear motion the tilt motion is created due to the alignment of the PIVOT Arms.

CONCLUSIONS

This prototype of a quick release tilt in space addresses the needs for safety i.e. (frame stability), collapsibility and easy storage, and easy use by a parent or attendant. Such a design aims to be incorporated into a variety of lightweight mobility bases. Development of this system considered existing commercial solutions to this problem.

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SIMULATION OF A RANDOM FATIGUE PROCESS APPLIED TO WHEELCHAIR STRUCTURES

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INTRODUCTION

The design of a structure is a matching process: matching the physical configuration to the desired function of the structure and matching the load carrying capability to the anticipated loading. This paper outlines a procedure for assessing the adequacy of a wheelchair frame's load carrying capability given that the design variables, for example structural material properties, structural geometry and load intensity are random variables. The goal is to deduce the statistics of the probability distribution describing the life of the wheelchair frame and integrate this information into a computer program used to calculate the reliability of an electric wheelchair system.

BACKGROUND

A personal computer-based system for estimating the reliability of competing electric wheelchair designs is currently under development. The computer system is capable of performing reliability analyses of the electronic, electromechanical and structural components of an electric wheelchair using the Markov model technique (1). This paper describes the method used to estimate the statistics of the structural life distribution.

The simulation described herein is based on the simplest fatigue model available, specifically fatigue life summarized by the S-N curve and damage accumulation according Miner's rule (2). This model was chosen because it is widely used, easily understood and provides a good starting point for more complex simulations. In the usual case of a Miner-/S-N analysis the load is of known (although varying) magnitude and the S-N curve is defined as a line. In the present analysis, however, the load is assumed to be a distribution of values whose probability of occurrence follows a normal distribution. Furthermore, the S-N curve, instead of a line, is modelled as a distribution of values throughout its range. At each stress level the S-N curve is assumed to have a normal distribution of values. Details of the simulation procedure are outlined in the next section.

SIMULATION

A finite element stress analysis (FEA) is performed on the entire wheelchair frame, loaded in the nominal static load case (3), yielding the mean value of the load distribution at each node. Next, the analyst specifies which design variables in the stress analysis are not known to be deterministic and are assumed to be random variables. Typical examples are modulus of elasticity and tube diameter and wall thickness. For each random design variable, the analyst re-runs the FEA with the value of one design variable perturbed from its mean value holding all other variables at their mean value resulting in a new stress value at each node. From these perturbed value runs, the standard deviation of the stress at each node is computed. Given the mean value and standard deviation of the stress at each node (assumed normal), the analyst selects the "node most likely to fail", usually the node with the highest mean value.

The nodal dynamic stress distribution describes the stress variations at a point and is determined by experimental strain gage studies (5). The data is normalized to the mean stress value and the dynamic load distribution becomes a distribution with mean greater than 1.0 and a standard deviation less than 1.0.

A classical stress concentration factor can be applied to any node with a stress riser. For purposes of this analysis, the stress concentration factor is assumed to be deterministic and equal to a constant. Using the rules for multiplication of constants and distributions (5), the nodal stress distribution, nodal dynamic stress distribution and concentration factor are multiplied together to give the combined stress distribution.

With a stress distribution defined and a normal distribution modeling the fatigue life at any given stress along the S-N curve, the simulation commences with the selection of a value at random from the stress distribution. From the equation of the S-N curve, the mean value of fatigue life at the random stress value is computed and, based on the assumed variability in the fatigue life parameters, a distribution of fatigue life at that stress value is formed. A random number is picked from the fatigue life distribution and the Miner damage fraction is calculated. The generation of random stress values continues until the sum of the Miner fractions equals 1.0 at which point the structural member is assumed to have failed. This constitutes one trial. For each trial the fatigue life is assumed to be the same number of standard deviations away from the mean value as determined in the first iteration. Typically several hundred trials will be necessary to yield a satisfactory estimate of the distribution of fatigue life.

RESULTS

For illustrative purposes a simulation was run on a hypothetical wheelchair structural element made of AISI 1018 carbon steel with an ultimate strength of 87,600 psi, an endurance limit of 30,000 psi and a load distribution with a mean value of 42,000 psi and a standard deviation of 5814 psi. A total of 1350 trials were made and the results were fit to a two parameter Weibull distribution (6) giving an average scale parameter of 8257 hours and an average shape parameter of 3.67. These data are plotted in the form of the probability density function f(t) and the reliability function R(t) in Figure 1.

CONCLUSION

A method of simulating the random fatigue process for structural elements has been described and an example of a wheelchair fatigue analysis was presented. Although it is computationally intensive, the method provides a useful tool for investigating possible empirical formulations for random fatigue design.

ACKNOWLEDGEMENT

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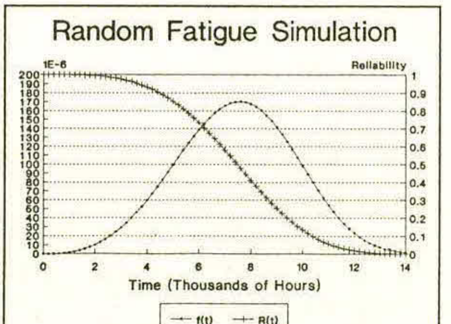

Figure 1

RACING WHEELCHAIR ROLL STABILITY WHILE TURNING

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ABSTRACT

The purpose of this investigation was to develop a simple roll stability analysis for three and four wheeled individual /racing wheelchair systems while turning on a flat, level road. We derive the equations for the critical roll stability velocity while turning for both types of chairs. These equations are functions of the mass and geometry of the individual and racing wheelchair. In general the critical velocity for a three wheeled chair is less than that of a four wheeled chair given the same geometry and mass distribution. The critical velocities are equal when the three wheeled chair has an infinite wheelbase or when the center of gravity of the individual/wheelchair system is located directly over the rear axles.

INTRODUCTION

Racing wheelchairs have been designed without formal roll stability analysis which has lead to some spectacular crashes due to athletes pushing their racing chairs beyond the stability envelope (2). Recent crashes have prompted some roadrace directors to limit speeds on certain portions of their courses, still others to prohibit the use of three wheeled racing chairs, and most have started requiring helmets. The restrictions placed on the use of three wheeled racing wheelchairs has angered several athletes (1). This paper presents a simple roll stability analysis for three and four wheeled racing chairs while turning.

METHODS

Roll stability analysis

Assumptions:
(a) The chair does not slip radially.
(b) The road is level and unbanked.
(c) The individual/wheelchair system is rigid.

Figure 1 shows the path of the individual/wheelchair system. Figure 2 gives the definitions for the location of the center of gravity for the individual/wheelchair system. For the individual and wheelchair to remain upright the center of gravity of the system must remain within the footprint of the wheelchair (one may imagine a lamp directly above the system, than the center of gravity must remain within the shadow as the system tilts). During turning the radial force at each instant can be described by equation (1).

$$Md^2r/dt^2 = Mv^2/r \qquad (1)$$

Model for a four wheeled racing chair.

For the purpose of this analysis it will be assumed that on each side of the chair the front and rear wheels are in line with one another (this is typically the case). Under this assumption, the critical roll stability velocity may be determined by summing the torques acting upon the center of gravity of the individual/wheelchair system about the axis connecting the outermost front and rear wheels. This is illustrated in equation (2).

$$MgD = Mv_4^2L/r \qquad (2)$$

Therefore the critical velocity for a four wheeled system can be described by equation (3).

$$v_4 = (gDr/L)^{1/2} \qquad (3)$$

Model for a three wheeled racing chair.

Figure 3 graphically presents the definitions for the geometry of a three wheeled individual/wheelchair system. The roll stability critical velocity for this system was determined by summing the torques acting upon the center of gravity about the axis connecting the outermost front and rear wheels (BC). This is illustrated in equation (4).

$$MgD' = F_pL \qquad (4)$$

The perpendicular force (F_p) is related to the critical velocity by equation (5).

$$F_p = (Mv_3^2/r)\cos\varphi \qquad (5)$$

(Note: $\lim_{WB_3 \to \infty} F_p = Mv_3^2/r = Mv_4^2/r$)

For greater utility we related the distance D' to geometry of the wheelchair frame and the position of the center of gravity of the system along the centerline of the chair from the line connecting the rear axles. The following equations show the derivation of these relationships.

$$\tan\varphi = D/WB_3 = D'/x \qquad (6)$$

$$x = [(WB_3 - d)^2 - D'^2]^{1/2} = D'WB_3/D \qquad (7)$$

$$0 \leq d \leq WB_3 \text{ (For static stability)}$$

After some algebra, we derived equation (8).

$$D' = D(WB_3 - d)/[D^2 + (WB_3)^2]^{1/2} \qquad (8)$$

(NOTE: $\lim_{WB_3 \to \infty} D' = D$ which is intuitive)

After substituting equations (5)&(8) into equation (4).

$$MgD(WB_3 - d)/[D^2 + (WB_3)^2]^{1/2} = (Mv_3^2/rL)\cos\varphi \qquad (9)$$

$$\cos\varphi = WB_3/[D^2 + (WB_3)^2]^{1/2} \qquad (10)$$

Therefore (after some algebra)

$$v_3^2 = (rgD/L)(WB_3 - d)/WB_3 \qquad (11)$$

(NOTE: $\lim_{d \to WB_3} v_3^2 = 0$, unicycle effect)

The relative stability of three and four wheeled individual/racing wheelchair systems.

The relative stability of three and four wheeled racing wheelchair systems follows directly from equations (3) & (11).

$$v_3^2 = v_4^2[(WB_3 - d)/WB_3] \qquad (12)$$

Some properties of equation (12).

$$\lim_{WB_3 \to \infty} v_3^2 = v_4^2 \qquad (13)$$

$$\lim_{d \to 0} v_3^2 = v_4^2 \text{ (c.g. chair)} \qquad (14)$$

CONCLUSIONS

Three wheeled racing wheelchairs are inherently less stable than four wheeled racing wheelchairs during turning on a flat level road. This analysis provides a means for determining an estimate of the critical velocity while turning given the geometry of the chair and the location of the center of mass for the human/wheelchair system. This analysis does not consider an active human controller, nor a multitude of other possible circumstances: turning on downhills, road irregularities, road crown, wind gusts, and other competitors actions.

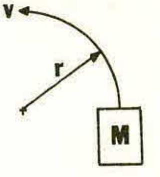

Figure 1. Path of the individual/racing wheelchair system.

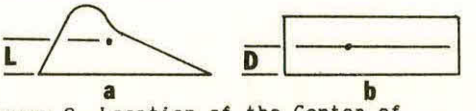

Figure 2. Location of the Center of Gravity w.r.t. the point where the wheels touch the ground for the individual/racing wheelchair system: a=side view, b=top view.

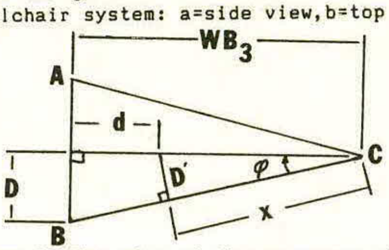

Figure 3. Top view of the geometry of a three wheeled chair. d is the location of the c.g. along the center line.

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A NEW MAINTENANCE-FREE WHEELCHAIR TIRE

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Introduction

Airless, solid rubber wheelchair tires offer maintenance and wear advantages over pneumatic tires, but do not give as comfortable a ride. Wheelchair users surveyed say that pneumatic tires are the biggest repair problem (Ref. 1). As such, the tire is a greater inhibitor of independent living than any other problem with wheelchairs.

Tests of tires (Kauzlarich & Thacker) (Gordon, Kauzlarich & Thacker) show that solid rubber tires give a much harsher ride than pneumatic tires, but foamed polyurethane tires give a similar ride. The main variable to be controlled for ride comfort is spring constant, since acceleration of the chair due to impact of the tire with a bump is proportional to the square root of the tire spring constant. However, the fatigue resistance of foamed materials is much lower than rubber, and the foamed tire can have a short life due to cutting and fatigue cracking.

A study (Kauzlarich) of solid rubber wheelchair tires using finite element analysis showed that increasing the hole diameter in the rubber will reduce the spring constant to that of a pneumatic tire. But, the tire stress will increase significantly as the central hole is enlarged, and the fatigue life of the gray rubber material will be significantly reduced. To improve the fatigue life of the rubber a new rubber compound is needed. The author and Dr. Metherell in England have produced a satisfactory compound for maintenance free tires, and the results of that work are reported in this paper.

Rubber Compound

A new compound has been developed for wheelchair tires using natural rubber reinforced with siliceous fillers and a special agent called SI-69. SI-69 is a silane coupling agent which solves the following problems usually associated with silica fillers in rubber: 1. Small additions of SI-69 will reduce the compound viscosity to the same or lower levels as compounds using carbon black, 2. The cure characteristics of SI-69 based compounds avoid reduction in cure rate and crosslinking density, and 3. At the same surface area as carbon blacks, SI-69 promotes the erection of filler to rubber bonds which causes a strong increase in the in-rubber surface area of the silica filler comparable to values close to the in-rubber surface of N-220 carbon black.

The new tire compound has a very high fatigue endurance limit. In comparison to all other nonmarking (non-carbon black filled) rubber tire materials the new compound: 1. Produces less heat build-up, 2. Gives higher endurance in service, 3. Has better tear, chipping, chunking and cutting properties, especially at elevated temperatures, and 4. Shows higher modulus retention at elevated temperatures.

Wheelchair Tire Performance

A comparison of the new wheelchair tire with a typical pneumatic tire is given in Table 1. The new tire design is under consideration by several rubber and wheelchair manufacturers in England, and is in the prototype stage of development. It is planned to introduce the tire in the USA when the tire is successfully developed.

Looking at Table 1, the most important advantage for the new tire is that it is maintenance-free. The tire performance is unaffected by accidental puncture. It has a very good wear resistance, more than 5 times that of a pneumatic tire, and would last the lifetime of the wheelchair. The tire is estimated to be more expensive than a pneumatic tire and tube, but the

TABLE I
Maintenance-Free Wheelchair Tire
Performance Characteristics Comparison

Maintenance-Free Tire (24 in.)	Pneumatic Tire (24 in.), Ref. 3
MAINTENANCE	
Maintenance-free	60 psig inflation pressure
WEIGHT	
880 grams (1.94 lbs)	734 grams (1.62 lbs) tire&tube
SKID MARKING	
Non-marking	Non-marking
ROLLING RESISTANCE per tire, 60 lbs load, 1.5 to 3 mph	
265 grams (0.59 lbs), calculated	263 grams (0.58 lbs), measured
COEFFICIENT OF DYNAMIC FRICTION, CONCRETE FLOOR	
0.85 (dry or wet)	0.65
TIRE SPRING CONSTANT (0-60 LBS LOAD) a low value indicates good ride quality	
730 lbs/in.	694 lbs/in.
ROLL-OFF (12 DEG. MAX.)	
No	No
ABRASIVE INDEX (WEAR RATE) higher values = lower wear rate	
110	19
COMPRESSION SET (23° C)	
13%	10.6%
COST TO CONSUMER	
$60 Est.	$40.10 (tire & tube)
LIFE, WHEELS ALIGNED	
Exceeds life of wheelchair	3-4 years

longer life would make it more economical to the user. In other characteristics, it is similar to a pneumatic tire.

Conclusion

Nonpneumatic tires offer important maintenance advantages over pneumatic tires. There is no need to check and adjust air pressure, and there is never a worry about a flat or punctured tire. These are very common inconveniences encountered when using pneumatic tires that reduce or disable the function of the tires. In the past it has been difficult to produce a nonpneumatic tire with a comfortable ride, but the new tire will overcome this difficulty.

Acknowledgement

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A DESIGN AND IMPLEMENTATION OF EYE MOVEMENT MONITORING SYSTEM WITH COMPENSATION OF HEAD MOVEMENT

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ABSTRACT

This paper describes design and implementation of the real-time digital data acquisition and monitoring system for eye movements. The main objects of the system design are as follows; (1) Eliminate the necessity of the adjustments, (2) Detection and correction of head displacement, (3) Integrate friendly use interface and database. An eye-mark recorder is used as the input device to measure the x-y coordinates of eye movements together with the front view. This system is capable of displaying and hard-copying various graphics in addition to regular raw numerical x-y coordinate data. In order to demonstrate the effectiveness of this design approach, the following eight types of graphics and numeric functions are implemented; (1) Locus of eye-mark, (2) Locus of eye-mark, (3) List of fixation pauses, (4) Locus of fixation pauses, (5) Direction of moving vector, (8) Frequency of velocity. This system is applicable to various experiments involving physiological, clinical researches.

INTRODUCTION

The monitoring of eye movements plays an important role in analyses of human cognition of visual information. For this purpose, eye-mark recorders with video cameras have been developed. Their field use, however, has a disadvantage of requiring tedious head fixation. The system reported in this paper eliminates the necessity of the fixation by means of connecting a personal computer to an eye-mark recorder.

SYSTEM CONFIGURATION

The measurement system consist of eye-mark recorder(made by NAC Co.), controller, personal computer, VCR and TV monitor. The personal computer(Toshiba J3100) controls an eye-mark recorder and acquires eye-movement and head displacement. Optional expansion box controlled image digitizer and GPIB interface board(Fig. 1).

The software of this system is written in Turbo-PASCAL(Ver 5.0). Data processing system divided into five blocks, marker identification block, data storage block, detection of head displacement block, data correction block and display block(Fig. 2).

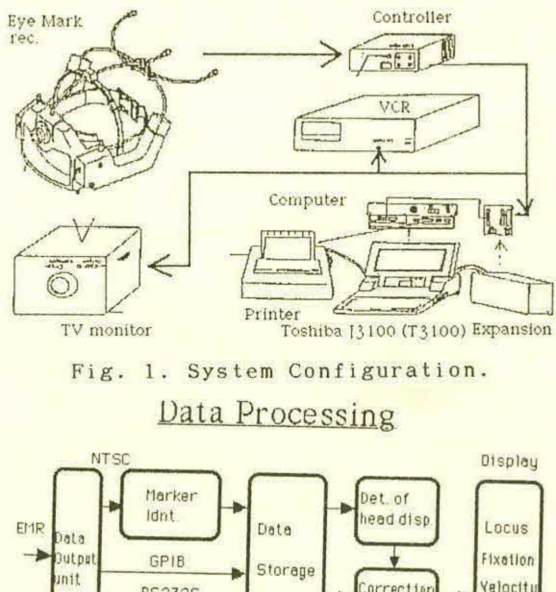

Fig. 1. System Configuration.

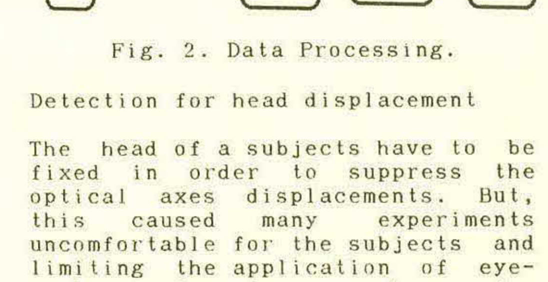

Fig. 2. Data Processing.

Detection for head displacement

The head of a subjects have to be fixed in order to suppress the optical axes displacements. But, this caused many experiments uncomfortable for the subjects and limiting the application of eye-mark recorder. An eye-mark recorder gives the X-Y coordinates of eye movements together with the front view. The front view camera moves with the head exactly. So we detect a head movement using a image of

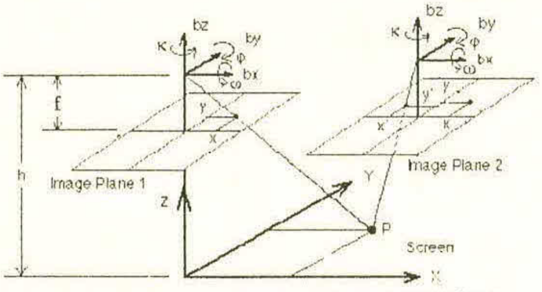

Fig. 3. Geometry of projection.

this camera. The following equations are details about three dimensional calculation for head displacement. Assuming original right handed coordination lies in a screen surface. Video camera locates in a height(h). Image plane of the video camera sets in a focus length(f). In this condition, a fixed point (p) and projected point will be calculated as follows.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = -t \begin{bmatrix} \cos\kappa & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix} \cdot \begin{bmatrix} X_i \\ Y_i \\ -f \end{bmatrix} + \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}$$

The relationship of the fixed point and projected point described matrix calculation include of axes rotation and displacements. Approximate the basic equations for further calculation.

$$dX = dX_c + \frac{X_i}{f} dZ_c - \frac{Z_c X_i Y_i}{f^2} d\omega + Z_c \left(1 + \frac{X_i^2}{f^2}\right) d\phi + Z_c \frac{Y_i}{f} d\kappa$$

Displacement for a reference point due to camera movement and parallax in photogrammetry are assumed to be a same meaning. Therefore parallax calculate as follows;

$$X - X' = dX_c + \frac{X_i}{f} dZ_c - \frac{Z_c X_i Y_i}{f^2} d\omega + Z_c \left(1 + \frac{X_i^2}{f^2}\right) d\phi + Z_c \frac{Y_i}{f} d\kappa - dX_c' - \frac{X_i}{f} dZ_c' + \frac{Z_c X_i (Y_i - d)}{f^2} d\omega' - Z_c \left(1 + \frac{X_i^2}{f^2}\right) d\phi' - Z_c \frac{Y_i - d}{f} d\kappa'$$

The parallax described ten parameters respectively. However, no more than five elements are used since relative orientation involves only five parameters. Five reference points enough to be calculated in camera location and rotation. Least square method applied for up to five reference points. Displacement and rotation to be calculate from eight reference points as follows:

from parallax x:

$$dX_c = -\frac{f^2(p1-3p2+p3+p4+p5+p6-3p7+p8)}{6b^2} + \frac{3b^2(p2+p7)}{6b^2}$$

$$dZ_c = -\frac{f(p1-p3+p4-p5+p6-p8)}{6b}$$

$$d\omega = \frac{f^2(p1-p3-p6+p8)}{4bdZc}$$

$$d\phi = \frac{f^2(p1-3p2+p3+p4+p5+p6-3p7+p8)}{6b^2 Zc}$$

$$d\kappa = \frac{f(p1+p2+p3-p6-p7-p8)}{6dZc}$$

Accuracy for measurement to be calculated from 2.2 to 87mm in location and from 0.003 to 0.18rad in rotation.

RESULTS

The numerical and image data are stored on real-time basis into a personal computer(Toshiba J3100GT). The software of this system is written in Turbo-PASCAL and its size is about 6,000 lines. The amount of executable program is about 120Kbyte. Data acquisition rate is three frame per second include data acquisition, calculate camera location and rotation and display data.

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INTRODUCTION

During a period spanning the last five to ten years a remarkably large number of microprocessor based adaptive devices has emerged to augment the more traditional methods used by rehabilitation specialists to enable the severely physically disabled to become more autonomous. When prescribed appropriately, devices such as key guards, alternative keyboards and microswitches have the potential to provide increased opportunities for independent functioning in daily life and work skills. Nevertheless, many of microprocessor-based adaptive devices currently available do not provide the severely disabled with the ability to carry out vocational and avocational tasks in a manner comparable to basic minimum speed and efficiency requirements. The development of novel access interfaces and modes of control is thus required.

The utilization of residual abilities to augment or replace those that have been impaired is a basic tenet of rehabilitation treatment programs. For example, the tenodesis action (wrist extensor driven digit flexion) is commonly used to provide functional grasp and pinch and standard figure-of-eight shoulder harnesses are used to provide control over prosthetic terminal devices. Regrettably the number and extent of possible compensatory actions have been inadequately explored. This is particularly unfortunate since recent technical developments in the fields of control theory, information processing and robotics mean that highly complex fine motor tasks could be accomplished with a relatively small degree of control by the human operator[4].

OBJECTIVE

The objective of the work described in this presentation is to describe a methodolgy designed to replace lost fine motor control with residual upper extremity function.

CLINICAL RELEVANCE

Consider an individual who wishes to communicate written information, operate simple electric devices, and manipulate objects. Rather than relying on the relatively slow traditional scanning and encoding methods or technically limited voice activation, it may be possible to perform these activities more efficiently in the following manner. The individual may, by means of generating different levels of isometric force via a given set of muscle synergists, locate up to eight distinct levels. The functional significance of these levels would vary for each task. For example, they may denote locations within the alphanumeric character set, channels on an environmental control unit, or positions of a robot manipulator. Such control can be thought of as open loop since the distinct levels are reached without external feedback. The use of only the eight levels of open loop control normally available to human operators[4] would, of course, limit the performance of most functional tasks. This limitation could be remedied by the addition of some external feedback (e.g. display of the character, channel or position first selected) which would then be used to "fine tune" the amount of force generated. For example, if the individual wanted to type the letter "F" he might quickly (without feedback) generate sufficient force to reach the "F" region which may, in this instance, correspond to "H". He would then relax slightly (with feedback) to produce the "F". Another example would be the use of open loop control to select channels of an environmental control system and feedback to alter parameters within each channel. The potential of human operator research is evident.

METHODS

Target Population This method is directed at individuals who have sustained partial loss of upper extremity function. Specifically, they would have negligible fine motor ability in the digits but have partial to compete motor ability shoulder complex musculature.

Apparatus Triaxial force measurements are recorded using a force sensing manipulandum comprised of three orthogonal strain gage force transducers mounted on a 50 mm wide customized fiberglass cuff. The manipulandum is affixed via velcro bands to the upper arm of the side retaining the greatest function just proximal to the medial and lateral humeral epicondyles. Subjects are seated in an adjustable, motorized chair with their forearms supported prone on a lap tray. Harness straps are used to stabilize the upper extremity and trunk. Signals from the strain gage (full bridge configuration) force transducers are amplified and filtered by analog signal conditioners having 140 dB common mode rejection ratio and built-in fourth order anti-aliasing filters set at 30 Hz. This filter roll-off is acceptable since the bandwidth of human force generation for muscles such as these is 0 - 20 Hz[5]. The signals are then sampled at 100 Hz by a 12 bit, 8 channel analog to digital converter having a software controllable, 3 bit gain. A VAXstation II computer running the VMS operating system is used for data collection and analysis and the entire experimental protocol is defined and executed in the VAX real time Common Lisp environment. Target signals are displayed to subjects on an auxiliary monitor. It has been demonstrated that updating the display at 10 Hz is sufficient for human tracking[2].

Experimental Paradigms

1. Identification of Optimal Force Axis Each subject undergoes a complete physical therapy examination. These data are then used to identify the upper extremity muscle group with the greatest range of force.

2. Determination of Force Range The range of forces in this muscle group is determined in order to obtain baseline information (minimum and maximum isometric forces) needed for the next paradigm. The minimum resting force applied by the limb of the relaxed subject when attached to the force transducer cuff is measured for a total of 5 s. Subjects are then required to contract maximally for 5 s.

3. Pursuit Tracking of Dynamic Target Stimulus It is necessary to demonstrate the proficiency (speed and accuracy) with which tasks representative of realistic motor skills can be performed. This is accomplished by means of a pursuit tracking task which identifies the subjects' ability to control and modulate isometric force in the selected muscle group. Subjects are required to match a computer generated random target signal having the following properties: (1) distribution of eight amplitudes within the range of forces determined during Paradigm 1, (2) frequency content ranging from DC to 1 Hz and (3) duration of 100 s.

ANALYSIS PROCEDURES AND RESULTS

The parameters for this pursuit tracking stimulus have been employed successfully[2]. A random distribution of eight amplitudes is used to ensure that subjects track the stimulus by eliminating their ability to predict the location of the next stimulus level. The selection of a DC to 1 Hz. bandpass was based on results[3] in which the relation between information transmission rate and stimulus cut-off frequency was systematically examined for position tracking tasks. The 100 s duration provides sufficient responses to compare performance over time and yet avoid the fatigue[1].

The dynamic relation (impulse response function) between the tracking stimulus (input) and the isometric force response (output) is determined using system identification techniques as described previously[5]. This function fully characterizes the linear dynamics of the subject's response: $y(t) = h(\tau)\, x(t - \tau)\, d\tau$ where $x(t)$ is the target as a function of time, $y(t)$ is the response as a function of time and $h(\tau)$ is the impulse response function (filter). Once these functions are identified it is straightforward to transform these into an information rate measure[4] which enables accuracy and speed of response trade-offs to be objectively determined. The pursuit tracking ability of ten subjects who have a variety of physical disabilites including high level spinal cord injuries, multiple sclerosis, amyotrophic lateral sclerosis and dystonia musculorum deformans will be presented.

CONCLUSIONS

Recent work by Mesplay and Childress[3] has demonstrated the potential of this experimental approach with regard to control inputs for limb prostheses. Preliminary results indicate that pursuit tracking will prove to be a useful input alternative for those who have reduced fine motor control.

ACKNOWLEDGEMENTS This work is funded by the Rick Hansen Man in Motion Legacy Fund.

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Assessing the effectiveness of postural biofeedback in functional activities: The use of hand-held computers.

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ABSTRACT

Biofeedback to alter posture is used to treat and prevent low back pain. It's effectiveness in actually changing posture is not established. A device and methodology to assess this are presented. Using a custom made analog to digital converter, a hand held computer monitors the activity of an inclinometer attached to the sternum. The sum of the cosine of trunk angles (sampled twice a second) divided by total time in a task, is uploaded to a desk top computer. The device was used with 10 subjects in a crossover study of instructions, corset, and audio biofeedback to determine that the audio method significantly decreased flexion compared to other methods in seven work simulating tasks. We conclude that the short term effectiveness of methods to alter posture can be validated with this device.

INTRODUCTION

Body position has played a key role in the prevention and treatment of low back pain (LBP). Epidemiological (4) and biomechanical (1) evidence suggest that various body positions and movements increase the force across the spine and predispose to injuries. In industry a number of preventive efforts have been aimed at improving body mechanics. Likewise, rehabilitation of LBP typically uses a variety of methods such as lifting education classes, braces, and postural biofeedback, aimed at decreasing stress on the low back.

Postural biofeedback has resulted in clinical posture improvements in persons with cerebral palsy (8). The effectiveness of efforts to change body mechanics in LBP have been demonstrated indirectly by a case study (3) which measures the effect of EMG feedback on EMG during movement. The effect of instruction on lifting tasks in industry has been questioned (7).

There is not a consensus on which movements should be avoided in LBP, and there is certainly not a consensus on what mechanisms are effective in preventing these movements. LBP is a significant social burden, and all interventions carry a cost. Thus, in addition to evaluation the effect of an intervention on pain, it is important to demonstrate that the effect is indeed due to postural changes, and not placebo or an alternative mechanism.

This paper describes the design of a device and methodology to assess the short term effects of interventions designed to minimize trunk flexion.

METHODS

The device

A Trunk Inclination Monitor (TIM) was fabricated by mounting a fluid filled angle measuring device (2) on a flat wooden strip 10 cm. long. This is attached to the subject's sternum by elastic straps which go over the shoulders and under the axillae to meet in the back. The TIM interfaces through a custom made analog to digital converter to a hand held computer (5).

Additional input to the computer comes from a switch which is held by the experimenter. The switch is depressed to signal the beginning and end of each task in the experiment.

The hand held computer calibrates the TIM so that 0 degrees is defined as the angle which TIM measures when the subject is standing upright. Angle measurements during trials are converted to a single factor (the "TIM factor") which represents both the time and severity of deviation from 0 degrees, and may have some biomechanical relevance to torque across the lumbar spine. The TIM factor is the sum of the sine of all angle measurements during a trial (sampled at two per second) divided by total time of the trial.

As described below, the hand held computer was programmed to organize TIM factors for six trials, each consisting of seven functional, but controlled tasks. After a subject completes the protocol, information is uploaded to a desk top computer for statistical analysis.

Protocol

The initial protocol was intended to differentiate the effectiveness of lumbosacral corset with metal stays from an inclinometer with audio biofeedback on trunk flexion. Audio signals were generated from the hand held computer itself. They increased in pitch proportionally with the angle of flexion.

Subjects: Ten healthy subjects, ages 18 to 40, 5 men and 5 women, were recruited and paid for participation. They were naive to the hypotheses being tested.

Tasks: Before beginning, subjects are told specific requirements for each of 7 tasks. These include shoe untying and tying, sitting down to type, typing on a word processor, standing up from typing, lifting 5 objects from the bottom of a barrel and placing them on the floor, lifting a large cardboard box a with 2 kg. weight in it, and placing pegs in a peg board at six levels.

Trials: The first trial was done without instruction. Before the second and all subsequent trials the subject is told to avoid forward bending as much as possible. TIM audio feedback is off and no corset is warn. The fourth and sixth trials are the same as the second. Corset and audio signal were randomized and alternated between trial 3 and 5.

RESULTS

Initial experimentation revealed inconsistency with the hand held switch which resulted in redesign of the switch and programming changes in the computer to factor out noise. Subsequently the device appeared to provide reliable and consistent data.

DISCUSSION

Data from the initial experiment has shown statistically significant ($p<.05$) differences in TIM factor between initial and instructed trials on all tasks. This suggests that the device is capable of measuring differences in postures. Detailed results of the clinical experiment are more appropriately presented elsewhere (6). Briefly, however, audio biofeedback with instruction to avoid bending was noted to be more effective than instruction alone overall and in most individual tasks. Corset with instruction was less effective than instruction alone in the lifting task and overall.

The device has produced meaningful measures of the effectiveness of various attempts to decrease trunk flexion. It has been proven useful in differentiating the effects of instruction, corset, and audio biofeedback from an inclinometer in a series of tasks of varying complexity, duration, and effort, which are similar to activities in daily life.

Output from the device is a simple and readily understood "TIM factor" which correlates to an extent with the mechanical stresses on the spine during flexion.

The device is portable, user friendly, and has programming flexibility. It interacts with larger computers for more complex data analysis.

Using this device one can now evaluate the effectiveness of a rehabilitation or prevention intervention which is claimed to alter flexion movement. The tasks

outlined are standardized and functional.

Because the technique involves evaluation of outcome in the short term only, it is possible that an intervention which is effective here will not be effective in the longer term due to extinction, distraction, etc. It is highly unlikely, however, that an intervention which does not demonstrate effectiveness in this short term structured evaluation will prove to be effective in preventing forward bending elsewhere.

It must be emphasized that trunk flexion is not the only biomechanical factor in producing LBP. Avoidance of flexion has not been conclusively demonstrated to decrease LBP clinically. This study demonstrates that if one considers flexion important, and if one attempts to prevent flexion, then the effect on flexion can be assessed. Using a similar protocol and modifications of the device, it should be possible to assess other motions.

CONCLUSION

Low back pain is a costly problem to the individual and to society. Given the multifactorial nature of LBP, we must be confident that the effectiveness of various interventions is due to their hypothesized mechanisms. This device provides a mechanism for assessing a number of interventions.

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CURRENT INITIATIVES IN ACCESSIBLE COMPUTING ON CAMPUSES

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INTRODUCTION

Since computers have become a crucial factor in most aspects of postsecondary education, the ability of students, faculty, and staff with disabilities to access computer equipment has become imperative.[1] Thanks to legislation such as Section 504 and 508 of the Rehabilitation Act, as well as increased consumer awareness, the need for accessibility is being brought to the attention of both computer center and disabled student service personnel. Two groups – Project EASI and the AHSSPPE Computer SIG – have recently been formed. These groups share information on accessible equipment on campus among group participants and act as a resource to those beginning to explore accessibility issues. In addition, some established on-campus programs are willing to share information on their experiences developing and providing services.

PROJECT EASI *(Equal Access to Software for Instruction)*

Project EASI was founded in 1988 by Krista Kramer and Nils Peterson as a subgroup of the Interuniversity Communications Council, Inc.EDUCOM). EASI membership includes representatives from the Higher Education and Adult Training for people with Handicaps (HEATH) Resource Center,[2] the Trace Center, and the vendor community, as well as people involved in existing or developing initiatives on a variety of campuses. The group has developed two publications: "Computers and Students with Disabilities," intended to facilitate communication between disabled student service staff and computing center personnel, and "EASI Fixes," a set of guidelines for software developers. Group activities under development include workshops on adaptive technology at conferences where such information has not traditionally been available.[3]

AHSSPPE COMPUTER SPECIAL INTEREST GROUP

The Association of Handicapped Student Service Providers in Postsecondary Education (AHSSPPE) has had a computer special interest group since 1988. The group's focus encompasses both administrative and personal uses of available computer systems. Led by Christy Horn of the University of Nebraska, the AHSSPPE Computer SIG periodically publishes a newsletter and has sponsored meetings and presentations at the last two AHSSPPE conferences. Plans for future projects include compilation and publication of a list of SIG members and supporters with expertise in specific computer-related areas.[4]

EXISTING CAMPUS MODELS

A number of college campuses have already set up adaptive computing services. Profiles and contact addresses for several of these campuses are included in the "Computers and Students with Disabilities" brochure published by Project EASI. Many of these listed campuses provide their own information packets as well.

California has a unique inter-campus program: the High Tech Centers for the Disabled. Fifty-five institutions of postsecondary education and three high school Regional Occupational Programs house High Tech Centers. The centers provide adaptive technology and information, and serve as research centers. The central facility, located in Sacramento, trains professionals in assisting High Tech Center users and provides technical support to High Tech Center employees. The program has also established criteria for selection of adaptive equipment, and publishes support materials for use by other campuses.[5]

Computer user groups can also play an important role in providing access. These groups provide persons at non-administrative levels, such as students and community members, with an opportunity to influence policy involving accessible computer equipment. The Barrier-Free Computer User Group (BFCUG) was founded in 1986 at The University of Michigan, when only a minimal amount of equipment was available in an obscure location. Thanks in large part to the efforts of BFCUG members, a centrally located Low Vision Room has been established featuring state-of-the-art equipment. Other BFCUG accomplishments include establishment of a mechanism for informing the campus computing center of new adaptive equipment that should be supported.[6]

Finally, major centers dealing with adaptive equipment are providing assistance to the campuses on which they are located. For example, staff members at the Trace Research and Development Center at the University of Wisconsin-Madison are working with disabled student service personnel and library staff to facilitate acquisition of appropriate adaptive computer equipment. This interaction includes Trace participation in campus automation and disability committees, and development of a set of accessibility guidelines to provide other campuses with timeline and budget models for establishing an accessible computing environment.

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Severe Disabilities and CADD: Initial Assessment

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Summary

This session will review the issues involved in selecting and configuring adaptive computer interfacing equipment to be used by persons with severe physical disabilities in applications of Computer Assisted Design and Drafting (CADD). Topics include: the selection process, equipment requirements, hardware and software issues, training issues, and issues of employment.

The computer used (complete with a host of adaptive equipment) in the evaluation process will be demonstrated.

Overview of Project

Persons with severe physical disabilities have been experiencing increased employment opportunities due to the integration of microcomputer technologies into an expanding number of professions. Vocational Rehabilitation facilities have been successful in adapting microcomputer equipment for control by individuals with many different types of physical and/or sensory impairments. Training has been available in areas such as computer programming, word processing and business applications.

This project focuses on enhancing the delivery of vocational rehabilitation services to persons with severe disabilities in still another area of advancing computer application, the field of drafting and design. Computer Aided Design and Drafting (CADD) now allows the trained draftsperson to be more productive than ever before. Using microcomputers in the field of drafting also now allows persons with disabilities who were unable to perform traditional manual drafting to participate in this exciting field.

Individuals with severe and demanding physical disabilities are now desiring access to CADD instruction for employment purposes. The process of interfacing such a person to a computer system is demanding and requires modern adaptive devices and computer configurations. Such approaches, for the most part, have not been thoroughly developed, evaluated, and tested. CADD programming requires high performance hardware and places intricate demands on the microcomputer and the user. This results in an increased degree of difficulty when attempting to interface a person with a severe physical disability to a microcomputer operating CADD software.

These same individuals, once provided with access to a CADD equipped microcomputer, have additional needs in terms of job accommodations and placement. Contractual or home-based employment is the most feasible method of securing paid employment. This form of placement is advantageous to the person with a disability and the employer, allowing for production to occur at an efficient rate in an environment conducive to the person's special needs.

This project incorporates an existing CADD training program, the services of a specialized rehabilitation technology services center, the involvement of a national engineering volunteer group, the involvement of current manufacturers of adaptive input devices for persons with severe disabilities, and the services of a community based economic development program which assists in development of new employment opportunities. These components are combined to initiate a successful enterprise to resolve access problems to CADD systems and to create a model for replication in the vocational rehabilitation service delivery community.

Focus of Session

This project has four major phases: (1) Selection and evaluation of adaptive devices, (2) Selection and evaluation of client candidates, (3) training, and (4) employment and/or production of saleable work. This session will focus only on the first two.

Even modest practical work with CADD applications requires hardware that has advanced processing power, fast processing speed, high resolution graphics, pointing device(s), and quality plotting capabilities.

AutoCAD, running on an IBM/MS-DOS compatible 80386 based machine, has been selected as being the most appropriate combination for training. *AutoCAD* is the industry standard program for computer aided design and drafting. The 80386 represents the current state-of-the-art in microprocessors and is the microcomputer platform that business is moving towards, especially in high-end applications such as CADD.

In the rehabilitation environment, it must be determined if methods of adaptive control can be integrated into the advanced microcomputer system which operates the CADD software. Any adaptive device(s) would have to interact in a compatible fashion with the CADD system without imposing any undue limitations on the system. In fact, it is more likely that the adaptive device(s) will be called upon to enhance the functions of the CADD program.

With CADD, the user is expected to be able to deftly manipulate a mouse and/or digitalization tablet in addition to the standard keyboard. Such movements are necessary for the selection of items from "pull-down" menus and the control of on-screen objects such as lines, arcs, ellipses, and polygons. It is crucial that any adaptive equipment, regardless of the actual method of input, allow the user to experience this same degree of control. Existing standards in the field of rehabilitation technology used for the selection of adaptive computer control devices for writing and communication may not meet the criteria required for CADD control. The identification, evaluation and experimentation with currently available adaptive equipment which meets all control criteria of a functional CADD system is a priority of this project.

With the help of collaborating vendors, systems were identified and obtained that would be most appropriate for producing work in a demanding CADD environment. The methodology of selecting among all commercially available products will be a primary area of discussion for this session. It is a goal of this project that it can be replicated easily. Using commercially available products is a high priority.

Candidates for this project are classified as having "severe disabilities". Such impairments include, but are not limited to, high spinal cord injuries (SCI), moderate Cerebral Palsy, and weak/small movement conditions (such as ALS, MD, MS, Polio, etc.).

The candidate for adaptive control of a microcomputer based CADD system must be evaluated to determine the most efficient and effective method of control. Such methods can include alternative keyboards, light pointing devices, proportional controllers and software modifiers. Usually the impaired user has some control over an anatomical site, such as he head or chin, or the person may have some control over their digits (but not the range necessary for normal keyboard use). Issues reviewed in the evaluation of possible anatomic sites include strength, range of motion, accuracy and tolerance for extended periods of activities.

Selection of the appropriate pointing devices is non-trivial. Issues of compatibility, ease of use, fatigue, integration with currently used systems, and personal preference must all be addressed. A wide variety of commercially available head pointers and trackballs exist, only a few are appropriate for use in adapting CADD. Speech recognition systems will also offers potential and the use of such systems will be discussed.

It is significant to note that the Center, and this project, has a strong vocational orientation. A person would not be considered for this project unless there was a fair chance of rehabilitation. Extreme physical impairment (such a person who could control only their eye movement reliably), or moderate learning disabilities, would eliminate a person from consideration for this project.

Conclusions

Pursuing a program of training which involves persons with severe disabilities and the ultimate goal of employment in the field of Computer Assisted Design and Drafting requires careful evaluation of both the user and the adaptive technology involved in the person/machine interface. This project is examining the crucial issues involved with both forms of evaluation and is creating a methodology which will ensure the selection of the most functional and complete control device to match the residual capabilities of the trainee with a severe disability. In subsequent years of this project, training curriculums and job placement strategies will be developed for the purpose of maximizing the application of the adaptive devices and CADD program.

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DISCOTHEQUE (DISABILITY COMBATING TECHNOLOGY) THE U.K. WAY

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For the past fifteen years I have been Chairman of the British Computer Society's Special Interest Group for Disabled People. I suffer from cerebral palsy myself and after gaining my Master of Arts degree in computer science and realising the enabling potential of computer technology, I decided to form this group which at that time was one of the first out of the current 50 within the Society.

The group has always been open for membership to people who are, or have a special interest in, disability. We look at areas such as technology in the home, aid to education and training and employment. Ideas were disseminated through quarterly newsletters which were circulated to our members and at our annual conferences which have always been well attended and blessed with speakers of the highest quality in their particular field. Apart from these two vehicles we have had easy access to professional journals and more difficult access to mainstream media. I believe this apparent indifference by mainstream media to be one of the main cultural differences between the UK and the USA. Despite this, the above activities plus a query answering service led to the group being so successful as to outgrow a part-time workforce and in view of this in 1988 I asked my company, GEC Computer Services, whether I could be seconded my duties with them to take on the work of the group full-time. They agreed and eventually in November 1988 I became Director of a project with a special brief towards looking at utilising technology to make it possible for people with severe disabilities to take on positions in professions which had previously been closed to them. For example CAD/CAM software enables a person who cannot use their hands but has the intellectual ability to design, to use the computer as a vehicle to liberate their imprisoned skills. Other examples are legal and accountancy, not to mention composition of music and graphic arts.

In effect the project is taking a more in depth view of employment than the group could possibly do, but of course this cannot be done in a void. Education and training are issues which I, as Project Director, have to address. Currently in the UK we have a skills shortage which is going to worsen during the 90s due to a so called "demographic time bomb" which will be at its height in the middle 90s and will mean that there will be 10% less school leavers than there are at present. This will increase shortage of skills which although unfortunate for British industries is a blessing in disguise for the physically impaired. Whereas five years ago companies were unwilling to consider employing people with severe disabilities, it has now become a relatively easy exercise for me to make them aware that within the UK two million people with disabilities of working age provide a pool of talent which is not being utilised. The vocations which I have already mentioned have often not been considered to be ones in which disabled people can be employed. When however the technology to achieve this is demonstrated they soon become interested and in general excited by the prospect of being able to fulfil their quota. (For those of you who are not aware, in the UK we have a statutory quota system regarding employment which states that every company employing more than 20 people have to include in its workforce 3% registered disabled.) Unfortunately in the past companies have not met this quota and it has been fairly easy to become exempt. Exemption, or failure to meet the quota, does not carry any penalty unlike most other European countries. Now however the tables have turned and people with the correct intellectual abilities are welcome, disabled or not. This is helped by our government scheme which provides finance for employers to purchase the appropriate equipment to allow disabled employees to work to their full potential. Grants up to £6,000 are also available to make any necessary structural alterations. Unfortunately, as yet, in the UK we do not have any registration regarding accessibility of standard computer equipment to people's disabilities. There is however an increasing awareness of the viability of incorporating such features on the grounds of user friendly systems for the disabled also user friendly for the able-bodied user which makes products more attractive and easier to market.

I would like to describe a tailor-made system which utilizes voice input and voice synthesis. APTECH was established as a result of a state-of-the-art study by the Commission of the European Community which examined the potential benefit to commerce and industry of speech technology. Dr Peter Kelway, APTECH's Managing Director, managed the project from 1984-86. The project identified a requirement for improved awareness of the capabilities of speech-based systems and a need for systems which were simple for those with no technical ability to implement and use. Efforts are currently concentrated on the needs of people with disabilities; their requirements set standards for hands and/or eyes-free systems for the business community in general. The disabled community are particularly concerned to acquire equipment which is suitable for both the able-bodied but which can be used by the disabled community without special adaptation.

APTECH's commercial products are based principally on the PHOENIX range of workstations which provide powerful solutions to those with severe disabilities and the visually impaired. APTECH has benefited from developing the workstation for disabled people, leading to a much higher performance than would otherwise have been considered commercially acceptable. The work-station enables users to have control through voiced commands of most commercially available computer programs such as Wordstar, Word Perfect, DBase 3/4, Autocad, Lotus 1-2-3, Symphony. Any other program which is designed to be keyboard-driven can also be run by voice. Voice output is produced via high-performance speech synthesis with screen-reading capability for output by single characters, words, sentences, paragraphs or whole documents. A variety of voices, speeds and intonations can be produced through a simple selection facility. PHOENIX systems can be supplied for installation on a variety of business computers or provided ready-to-use as workstations. Equipment ranges from a low-cost plug-in speech synthesiser for screen reading to a professional workstation using voice recognition and response, incorporating the remarkable 30,000 word DRAGON-DICTATE system. For many applications, both keyboard and screen can be dispensed with, allowing maximum freedom for the disabled person to become gainfully employed in a professional environment.

Finally I would like to suggest that the infra-structure inherent in a professional society such as the British Computer Society is an ideal one to produce a highly efficient, cost effective system which allows people with disabilities to integrate with their peers on equal terms. The membership which comprises of individuals placed into geographical groups and having special interest groups available to them, affords people such as myself to tap the expertise of individual members, to obtain the knowledge of world leaders in their particular sphere, and to encourage awareness among a population which would otherwise probably not give a lot of thought to the question of disability.

Acknowledgements

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MANLIFTS FOR AGRICULTURAL EQUIPMENT

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ABSTRACT

Four innovative designs of powered lifts used to gain access to agricultural tractors, combines, and other self-propelled equipment are described in this paper. Two of the lifts are variations of a vertical screw lift. The third is a parallel linkage lift activated by an electrical linear actuator. The fourth is a combination of the first two types. Each design is in production and being successfully used by farmers with serious physical disabilities.

INTRODUCTION

During the early 1980's the Breaking New Ground Resource Center, with support from John Deere & Company and the National Institute of Handicapped Research, developed several prototypes of lifts which could enable a farmer with restricted mobility to gain access to the operator's station of agricultural equipment. Farmers with disabilities find access very difficult considering the large size of modern equipment. In 1987 a small machine shop in West Lafayette, Indiana agreed to develop the concepts commercially. The firm has since completed over 50 units, in a variety of configurations, with considerable improvement over the original designs. The vertical screw lift has proven to be most successful.

THE VERTICAL SCREW LIFT

There are two styles of vertical screw lifts, the standing platform and the chair. Both styles can be used on either tractors or combines, with or without cabs. The lift assembly of either style can be transported far enough above ground level to avoid field trash, yet be lowered to a position allowing easy transfer to or from a wheelchair.

Lifting is accomplished by a reversible 12 volt electric motor turning a heavy duty ball screw in a vertical position. Upon this screw rides a low friction nut. Attached to the nut is the slide, which supports either a platform in the case of a standing platform lift, or a swing arm assembly in the case of a chair lift. As the motor rotates the vertical screw, the platform, or the chair, is either raised or lowered. Lifting speed is about 4 fpm.

The vertical screw is enclosed in a painted sheet metal housing with a flexible plastic flap to protect the screw from dirt. This assembly is called the mast. Two mounting brackets, an upper and a lower, secure the mast to the vehicle. The vertical screw lift is relatively easy to mount on different types of equipment by modifying the mounting brackets. There have been a variety of applications for the lift: tractors, combines, vans, pickup trucks, and even boat docks. The length of the vertical mast can be varied to fit the application. The average mast length for tractors and combines is about 10 feet. The mast is purposely located in an already existing blind spot to reduce its interference with operator vision. On combines the lift mast can be located either to the front or to the rear of the cab door, depending on the design of the door, crop header, and the unloading auger. On tractors, the lift mast is installed to the front of the cab door, away from the rear drive wheels.

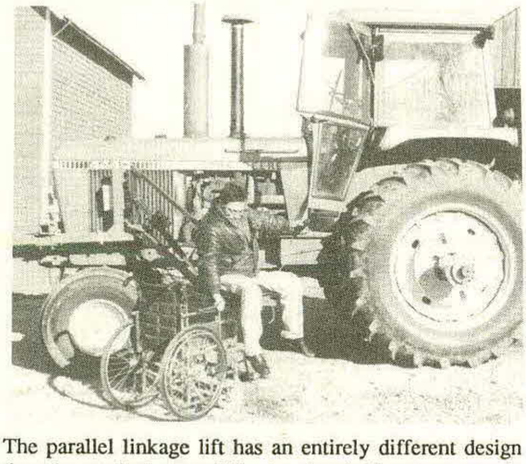
The vertical screw standing platform lift
This lift has the simplest and the most economical design. It consists only of a mast and a platform to raise and lower the user. One electric motor to turn the vertical screw is all that is required for its operation. The remote control has only two push-button switches, one for raising, and one for lowering the platform. For the standing platform lift the user must be able to stand. The user can step onto the platform at ground level, and raise himself to the equipment's cab floor.

The vertical screw chair lift

The vertical screw chair lift consists of a seat connected to a swing arm assembly. Each swivel joint of the swing arm contains double roller bearings. Inside of the swing arm control box are two electric motors and six electric relays. The relays control the three electric motors of the chair lift. The motors drive worm gears, a design which prevents any chair motion when the motors are stopped. The mast motor turns the vertical screw, raising or lowering the seat. One swing arm motor moves the chair towards the cab doorway. The second swing arm motor rotates the chair, allowing the user to obtain the most convenient position for entering the cab. All motors contain internal slip clutches to prevent injury to the user, or damage to the lift, in the event of lift binding.

Chair lifts are equipped with a hand held remote control connected to a control box by a heavy duty stretch cord. The remote control has six push-button switches, enabling the operator to move the chair in six different directions. More than one motion can be chosen at the same time. Cab doors can be either a front or a rear opening design. The swing arm mechanism can rise above the open door of the cab, swing the user around the outside of the door, and into the cab doorway. The chair lift can be transported away from the doorway, allowing other workers to enter or exit the cab without using the lift.

THE PARALLEL LINKAGE LIFT



The parallel linkage lift has an entirely different design than the vertical screw lift. An electric linear actuator is located at diagonal corners of a flexible 4-sided frame made of steel square tubing. This allows the lift seat to be raised about six feet above ground level. In general, the parallel linkage lift is adaptable to tractors having cabs with front opening doors, or cabless tractors. This lift has not been used on combines. The lift is mounted toward the front end of the tractor. A special linkage located at the tractor mounting bracket causes the chair to automatically swing toward the cab doorway as the lift is raised, and to swing away from the doorway as the lift is lowered. The seat can be rotated about a support hinge to enable the rider to obtain the most convenient approach to the cab doorway. This also allows the seat to be transported away from the doorway so that other persons can enter or exit the cab without using the lift.

One hand held controller connects to the lift actuator by a stretch cord and can be operated from a wheelchair in the general area of the lift, or from the lift seat. A second controller is mounted in a convenient place near the operator's seat of the tractor.

THE HYBRID LIFT

The hybrid lift is a recent development. It is a "cross" between the vertical screw lift and the parallel linkage lift. A unique feature is that the lift and the tractor make use of the same seat. The lift seat is the tractor seat. There is no need for the rider to transfer except from a wheelchair at ground level. The ability of a swing arm assembly to maneuver the seat is combined with the light weight and low clearance of a parallel linkage lift. The parallel linkage raises the seat up from ground level. The swing arm assembly is used to position the seat over the operator's station of the tractor. Finally the seat is lowered into a cradle provided on the tractor.

The hybrid lift can be used on relatively small tractors. The first unit was installed on a John Deere 950 which has 27 hp. Since the hybrid lift seat is also the tractor seat, it can only be adapted to tractors without a cab.

ACKNOWLEDGEMENTS

The commercial development and manufacture of these lifts is is being achieved by:

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Ten Years of Rehabilitation Technology in a Developing Country : A Review, 1980 - 1990

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Abstract

Western techniques and technologies have been successfully applied for reducing disability in third-world situations. However, ten years of experience have led us to the conclusion that simple-minded transfer of ideas and devices from developed to developing countries is at best only partially successful and at worst doomed to outright failure.

We cite pertinent examples of successes and failures with the aim of helping others to avoid these pitfalls. We stress the importance of the study of the social anthropology of communities and to take cognisance of how successful programs need to dovetail into existing structures if they are to achieve success.

Mobility

Certain diseases are unique to this area. For example, Mseleni Hip Disease is endemic to the Northern Zululand area. Young women suffer crippling degenerative arthritis of the hip of unknown aetiology during their most productive years. Very often, by the age of 35 they are reduced to crawling around in the local sandy ground, not able to fulfil their responsibilities in the economic/family unit. This leads to further impoverishment and deprivation/disability in their progeny. Welfare programs and donations of Western technologies have been relatively unsuccessful in making any real impact. For example, the wheelchair, as used in North America is totally useless in the rural setting. These devices bog down in the sand, the tyres are damaged by stones and thorns and are literally reduced to scrap within one year by the rigors of use. We are currently in the process of designing a more appropriate mobility device.

Augmentative and Alternative Communication

In subsistence economies, as exemplified by most of rural Africa, a disabled child whether by birth, disease or trauma, is a drain on already limited resources. Also, in some cultures, these children are a source of shame to the mother and family, and are thus kept "out of sight". In trying to offer these children a better future by education and training for alternative employment, ie not doing manual work, it is important to breakdown and through these prejudices. There are too few teachers in general and very few have any background in Special Education, and so, even simple picture-boards leading to Bliss Boards are the exception rather than the rule.

However, in AAC, by the establishment of a Community Service organisation called INTERFACE we have, over the last few years, achieved some creditable successes. INTERFACE now has four Branches in the region and maintains a resource and expertise reference centre in major cities to advise teachers, therapists and parents how to promote normal development of communicatively-disabled children and to assist adults with degenerative diseases. Technologies range from low, ie. paper and pictures to high, ie. sophisticated devices and PC-based office equipment.

One area which needs urgent attention is the large number of ethnic languages in the region (over 10). Since many systems, be they picture-book or electronic/computer-based, are conceived in English with western semantic structures, it is inappropriate to try to apply them without very costly adaptation or rewriting/reprinting for the local context.

Translating them into the 'vernacular' (in the widest sense of the word) will take a great deal of creative effort by people with intimate knowledge of the prevailing cultural and language/environment Some devices, eg the INTROTALKER (

PRENTKE ROMICH COMPANY) lend themselves to easy use in a regional dialect since they can easily be customised by locally-relevant pictures (for selection) and digitally-sampled real voice - giving realistic speech output. The problem is that such devices are relatively expensive since they are memory-intensive, and so cannot easily be extended for general AAC use at affordable prices.

Other communication devices, which use the rules of English for improving pronounciation, fall down badly when their text-to-speech converters try to deal with foreign languages. Asking teachers or parents to custom-program them phonetically to overcome this problem is just not practicable!

General Awareness of the Hope of Technology

We have the only Rehabilitation Technology Department in Southern Africa at the University of Cape Town and provide an educational service for both academic and community needs. In addition, we support local organisations which provide welfare and/or rehabilitation support. Ten years of experience have taught us that it is better to teach people, "How to fish" rather than to supply the packaged product. Wherever possible we try to build up programs, avoiding one-on-one assistance, unless absolutely necessary. However, we have several examples of pieces of hardware that, though built for an individual, proved to be more generally useful afterwards. Examples of these are a vertical (upright) wheeler for paraplegic children, a mains-water powered bath hoist and an Infra-red Communication and Environmental Control Interface.

Frequent contact with others working in the field via RESNA (we have been associated with RESNA and, in particular, the VA HOSPITAL, PALO ALTO/ STANFORD UNIVERSITY for 8 years) have enabled us to keep abreast of the latest advancements and to abstract from them those aspects which could successfully be applied in our developing region. Without this valuable exchange of ideas Rehabilitation in Southern Africa would be the poorer.

Acknowledgements

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Applied Technology in the Prevention of Secondary Injuries for Farmers with Physical Disabilities

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Introduction:

Farming has been designated as the most dangerous occupation in the United States. It is estimated that there are over 560,000 agricultural producers with permanent physical disabilities. In the past ten years, efforts have been made to design and fabricate rural rehabilitation technologies that will enable farm tasks to be completed by farmers affected by various physical disabilities. This technology has also been successful in prevention of secondary injuries. Unfortunately, many farmers with physical disabilities continue to experience secondary injuries. This paper, while based on interviews with Iowa farmers who have experienced a physical disability, will focus on the use of applied technology in preventing secondary injuries on the farm.

Causes Of Secondary Injuries:

Lack of sensation, reduced lung capacity, inability to perspire, spasticity, and limited mobility are associated with secondary injuries that have affected farmers with spinal cord injuries. These injuries include: skin break down, heat stroke, bruising, fractures, and infections.

Decreased vision or no vision while completing farm tasks can result in cuts, bruises, and fractures.

Decreased lifting ability; tractor jarring and vibration; climbing; and excessive pushing, pulling, bending, or reaching can result in further injury to a farmer who has experienced a back injury.

Farmers who use an upper extremity prosthesis have been injured when the prosthetic device catches onto something with the inability to let go or when the prosthesis comes in contact with an electrical current. In addition, farmers who use above elbow prosthetic devices can experience injuries to their feet when an elbow lock breaks while carrying a heavy object. Reduced grasping ability has resulted in falls while completing tasks that require climbing. Frost bite to one's stump can occur while performing tasks in extremely cold conditions.

Farmers with above knee amputations can experience falls while performing tasks that require climbing, walking on uneven terrain, and when knocked down by livestock. Additional injuries to one's stump, for farmers who use an above knee quadrilateral socket, have resulted from pinching that often occurs while operating a tractor.

Technology Related Solutions:

The following solutions have been recommended by farmers with various disabilities, to prevent secondary injuries.

Visual Impairments

A hard hat and shin guards that are used by hockey players can reduce injuries to the head and shins due to various hazards around the farm that are not always seen or detected soon enough. If protruding objects cannot be eliminated or guarded, padding material can be applied to the object which will reduce the severity of a potential injury.

A farm dog is highly recommended to alert the farmer as to potential hazards with animals including: the possibility of being knocked down by livestock; animal bites from muskrats; or snake bites. One farmer had his dog trained to attack and kill snakes.

Spinal Cord Injuries

Foot guards need to be mounted on all terrain vehicles to prevent one's foot from slipping off the foot rest and getting caught under the back wheel of the all terrain vehicle.

A quick release restraining belt around the lower legs or padding of the hand controls in a tractor can reduce bruising which can occur due to spasticity. In addition, a man lift can be mounted on a tractor to eliminate excessive bruising while mounting and dismounting from a tractor without a lift.

An air conditioned tractor cab and plenty of drinking water are recommended to prevent heat stroke on hot, sunny days. For tractors without a cab, a canopy or umbrella and several spray bottles of water are recommended to compensate for decreased ability to perspire. In addition, work should be performed during early morning or late evening hours for reduced sun and heat exposure.

A Roho cushion can reduce skin break down in a tractor seat. An independent suspension seat might also be considered to increase upper body stability and absorb additional jarring and machine vibration.
An air stream dust helmet can be used by farmers who are susceptible to pneumonia or who have a decreased lung capacity, when working in dusty environments. Farmers who use puff and sip controlled electric wheelchairs, should have this control disinfected daily.

A business band radio, CB radio, or portable cellular phone should be used while performing tasks in an isolated area in case of an emergency. A loud horn or siren can also be mounted on a wheelchair to alert co-workers in case of an emergency.

A long, leather apron and leather boots should be worn when welding. The leather apron should extend over the wheels and foot rests on the wheelchair. Alaskan Mukluks, modified sleeping bags for lower extremities, and quilted leg warmers can be used to protect one's lower extremities from possible frost bite.

Upper Extremity Amputations

A quick release harness which fastens in the front of the chest can be used by farmers with below elbow prosthetic devices, when the terminal device gets caught onto such things as a cow's tail, a cow's chain, or branches with the inability to let go. Additional modifications that can be made to a prosthesis which can prevent additional injuries include: the use of a nylon rope instead of a cable, which reduces potential electrical shock, and constructing an external elbow lock that would be more reliable when carrying heavy objects.

Frost bite to one's stump can be prevented through increased insulation within the prosthetic socket; external insulation applied to the outside of the socket; and the use of additional stump socks. Disposable, 2" x 3" hand warmers can be placed inside of a glove for farmers with finger amputations, to prevent possible frost bite.

To prevent injuries that occur when climbing, wider steps made of non-slip material can be added to the tractor and stairs can be added to a grain bin.

Leg Amputations

All terrain vehicles, golf carts, riding lawn mowers, and adapted cane tips can be used to prevent falls which frequently occur while ambulating around rough, rural terrain, for farmers with above knee amputations. Wide steps constructed of non-slip material and hand holds can be added to the tractor to increase safe footing when mounting and dismounting. Automatic gate openers, spring loaded gates, or hinged gates can be installed to eliminate potential falls while climbing over a gate. Grain bin level indicators, bin stairs, and a bin elevator can be installed to eliminate vertical climbing.

Fence line feeding or other feeding methods that would eliminate direct access to livestock should be considered in preventing the possibility of being knocked down or stepped on by livestock.

A Normal Shape Normal Alignment Socket, has been successful in reducing pinching that oftens occurs to the stump while operating a tractor.

Back Injuries

Labor saving devices including: overhead hoists, feed carts, lifting devices, round balers, automated feed systems, etc. can reduce reinjury to one's back when performing tasks that normally require repetitive bending, pushing, carrying, lifting, and reaching.

Independent suspension seats should be considered to absorb excessive jarring and vibration. These seats should have adjustable arm support, adjustable lumbar support, and adjustable thigh support. Control levers and a full view mirror can be used to reduce excessive twisting.

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THE RANGE EXCHANGE: REHABILITATION INFORMATION CONNECTION FOR RURAL CONSUMERS

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INTRODUCTION

Assistive technology can have a dramatic and positive impact on the lives of individuals with disabilities. For rural consumers major barriers to acquiring assistive technology are the lack of a coordinated delivery system and insufficient funding for assistive technology. Proper service delivery in rural areas can be enhanced if information on assistive devices and services is made available to consumers, service providers, employers and other representatives. The RANGE EXCHANGE offers a new approach to meet this need.

BACKGROUND

In developing a delivery system for assistive technology in Montana several unique constraints must be considered. Rural populations are no less isolated from rehabilitation problems than their urban counterparts, but what makes them unique is that they appear to be isolated from the solutions. There is a scarcity of professional service providers, support groups and peer counselors. Great distances between service providers and associated agencies establish an inherent barrier to a critical ally, "networking". The key element is choice. With rural residents, "choosing between services or service providers is a laughable concept; getting any service at all is the critical question" (Tonsing-Gonzales, 1988). Public transportation for accessing rehabilitation facilities and services is non-existent. If rural residents are fortunate and can provide their own transportation, they will still be facing the added inconvenience of extra time, distance, lodging and perhaps assistance to access services. It makes the urban concept of "comparison shopping" out of the question.

A number of assistive technology service delivery systems in rural areas were reviewed to identify common features and strengths that could be incorporated in an assistive technology service delivery system for Montana. Major strengths of these programs included: strong commitment and dedication to rehabilitation goals by the program coordinators; personal attention to the clients (usually one-on-one relationships); thorough knowledge and efficient use of available resources by the service providers; a true awareness of the needs of the people; and the effective use of volunteers. The volunteer component was an especially noteworthy feature of rural rehabilitation programs. Volunteers are valuable because they are knowledgeable about local populations and their needs, tend to have high energy levels and strong commitments to their mission and have a history of producing desired results. Volunteers can contribute in a variety of capacities based on their skill level and available time and are a practical alternative to professional service providers in rural environments where services and information channels are limited.

Part of the solution to the problem of delivering rehabilitation services comes from the rural population themselves. They are independent and self-sufficient. They are a sturdy lot, tolerant of extremes in weather, economy and transportation. They have made a compromise to live in a rural area. They live by the "I can take care of myself" philosophy. Rural residents may not know where to turn when assistance is needed and are less likely to ask for help in that situation. These individuals make do with what already exists and build the necessary adaptations with whatever materials are available.

A NEW APPROACH

Researching rehabilitation information and retrieval systems and service delivery programs in rural areas highlighted a special need for information dissemination: information doesn't do anybody any good if they don't know their options. The problem was identified: there are people with disabilities living in rural areas who are not aware of rehabilitation and assistive technology solutions which might improve their lives and enhance their independence.

Research also indicated that people living in rural communities sincerely care about one another and are usually willing to assist those in need. Grassroots organizations are an integral part of rural culture. It is the concept of the community spirit living on. Thus it follows that they can provide a viable mechanism by which to assess and meet the information needs of people with disabilities in rural areas.

How do we disseminate information to rural areas? Because the rehabilitation needs of rural Montanans cannot be adequately met by service providers, it is critical not only to disseminate information to professionals, but also to the grassroots level: the PEOPLE.

By choice the rural population often accesses a unique group of service providers for information. These "Generic Providers" include diverse community members such as County Extension Agents and Ministers. Understandably they have little, if any, knowledge on assistive technology. Yet they provide important services to rural people. They are trusted individuals who have advised the rural population on issues such as crop rotation, county fairs or marital problems. They do not represent "Uncle Sam" or bureaucratic paper pushers. And they may live right down the road. Questions on assistive technology don't come to them every day, or even every week. But the point is, the rural population contacts them because they need information and don't know where to go. They are UNAWARE!

Assessing and evaluating these grassroots organizations as well as rehabilitation and assistive technology services in rural environments resulted in identifying a potential link of efforts by two diverse groups within the state: the RTC:Rural and the Extension Homemaker Club within the Cooperative Extension Service. The combination of the credibility of the Extension Service and the seemingly unlimited potential of a 4400-member volunteer force such as the Extension Homemakers generated the idea for The RANGE EXCHANGE. A partnership has been formed by these organizations to participate jointly in The RANGE EXCHANGE project in a designated five-county area of southeastern Montana to be completed July 1, 1990.

The basis for The RANGE EXCHANGE project is the "community-based link" which is created between people with disabilities and information on rehabilitation resources. Because of their familiarity with the community, the Extension Homemakers have identified people with disabilities in their area. Extension Homemakers work in pairs conducting "home visits" with people with disabilities living in the test area. They act as information providers by displaying various publications and catalogs illustrating adaptive equipment to people with disabilities The rural consumer identifies the problem tasks which are most critical to them. By demonstrating how to locate a particular product in a catalog and determine its appropriateness the Homemaker helps the consumer take the first step to finding a solution. The "link" is thus established.

During the home visit the Homemakers gather information about the adaptive devices the consumers are currently using, how effective these devices are, and any modifications or "do-it-yourself" designs which proved useful. This information becomes the basis of several RTC:Rural studies to determine how to better address and meet the needs of people with disabilities in the areas of assistive technology and rehabilitation services.

Prior to conducting home visits, each Extension Homemaker attends a full-day training program which includes a dry run in-home visit. The training provides general background information on what disabilities are and what effect they have, what assistive technology is and how it can help, and how to find appropriate information and information sources. The Homemakers are not expected to become "experts" on rehabilitation, but rather to create an awareness, and "open the door" to assistive technology.

The RANGE EXCHANGE offers a new approach to providing information on rehabilitation services and assistive technology for rural consumers. It draws on the strengths of rural society and develops them to their fullest potential to meet the needs of people with disabilities.

ACKNOWLEDGEMENT

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A STUDENT DESIGN PROGRAM FOR RURAL PEOPLE WITH DISABILITIES

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INTRODUCTION

Providing assistive devices to people with disabilities who live in rural areas presents many challenges. Because of the occupation, lifestyle and level of income of these people, commercially available assistive devices may not function as needed, or the cost may exceed the financial means of these individuals. Often, because of the unique needs of people living in rural areas, there is no commercial device available to fill the need.

This paper describes a program at Montana State University that uses senior Mechanical Engineering students to design and build low cost assistive devices to meet the needs of individuals with disabilities living in rural areas.

PROGRAM OVERVIEW

The goals of the program are to provide a client with a custom designed piece of adaptive equipment that will fill a particular need, and to give the students involved a comprehensive grounding in engineering design.

The program runs a full academic year, with the first ten weeks devoted to the design of the device, the next ten weeks devoted to construction and the final ten weeks devoted to testing and modification. At the end of the project the device is given to the client.

Potential projects are typically obtained through contacts with therapists, independent living center personnel and county extension agents. Suggested projects are screened by faculty involved in the design course to determine their suitability for the course. This screening attempts to identify those projects that are not suitable for the course because they are too straightforward, don't involve significant *engineering* design and analysis, exceed cost or time constraints, or pose excessive liability exposure. Projects that are found suitable are added to a running list.

At the first class meeting students form design groups of three people and each group selects three projects from a list of available projects. The information given to the students is a one sentence needs statement. These three projects are pursued for the first ten days of the academic term so that the students can learn more about each project. During this time students contact the clients and also appropriate health care professionals in order to clearly identify the need and develop a problem statement. A proposed solution is developed along with a rough budget, and project milestones are identified. These are presented in a one page project abstract. Development of the abstracts enables students to look at several projects in some depth to determine which one is most suited to their interests. It also provides a second screening that may identify additional projects that are not suitable for the course. After developing the project abstracts, the group chooses one of the three projects to pursue for the remainder of the course.

At the end of the first ten weeks, students are expected to prepare a comprehensive design report, including the necessary design analysis and engineering drawings.

Classroom meetings with the students focus on developing an understanding of the design process as a logical progression from needs identification to final design and construction. In contrast to other courses in an engineering curriculum, design is unique in that the problems have no single "right" solution, and often the professor doesn't have the answer to a student's questions. Consequently, students must learn to cope with the uncertainty and changes that are inherent in design.

One of the advantages of assistive device design is that many problems are straightforward enough that students can refine their design skills by solving problems that are challenging yet manageable. In addition these projects have a direct benefit to society, an important consideration for many engineering students.

During the second ten weeks of the project students concentrate on building their design. Most of the work is done by the students themselves, using the shop facilities available at the university. If a project requires advanced manufacturing skills the help of university shop personnel is available.

Once construction is completed the device is tested by the client and the students, with appropriate input from health care professionals. This typically occurs during the final ten weeks of the project. Based on this testing, modifications are made to the device. Once the device is working properly, a project report is prepared that is an extension of the design report. In addition to the material included in the design report the project report includes the final engineering drawings, construction details, test results and an objective assessment of the design.

IMPORTANT CONSIDERATIONS

There are several important considerations that must be addressed in order to implement a program such as this.

Most of our students have no previous experience in working with people with disabilities, and have no clinical knowledge of the various types of disabilities. Therefore, we ask a local rehab professional to talk to the students during the first week of class about living with a disability. We are also fortunate to have a rehab professional available to advise the students during the course of their project work.

It happens occasionally that a project may not be "successfully" completed, although the educational goals of the course have been met. Conversely, it may also happen that a project may meet the needs of the client, but that the educational goals of the course are not met. The question of client expectations vs. educational goals is an important one to consider. Students need to understand that they are going through an educational process and that it is not sufficient to merely complete a *project* successfully, but that they must also complete the *educational process* successfully. Conversely, potential clients need to understand that successful completion of the educational process may not lead to a design that meets their expectations, and that suitable projects will take about one academic year to complete. Projects that are too simple won't allow students to meet the educational goals of an *engineering* design course, nor will those that are too difficult. If the projects are funded through a grant there may be grant obligations that must be considered that conflict with either educational goals or client expectations.

In order to minimize potential conflicts it is important that the responsibilities of the professor, students, rehab professional and client are made clear at the outset of the project.

APPLICABILITY OF THIS APPROACH

All students graduating from accredited engineering programs must complete a senior capstone design course in which they complete some sort of design project. Further, all states have at least one university that has a Mechanical Engineering program and these universities usually offer both Mechanical and Electrical Engineering. Since these are the two engineering disciplines that are most relevant to the design of assistive devices, the probability is very high that the engineering educational programs necessary to engage students in the design of assistive devices exist in every state.

Because of the constraints of engineering education, not all rehab design projects are suitable for engineering students. Those projects that are suitable must have the potential for a significant amount of engineering design, must not have severe time constraints, must not be beyond the capabilities of engineering students, and must have an adequate (but not excessive) budget.

Projects that are not suitable for an engineering program because they don't involve enough engineering design may be suitable for vo-tech programs at community colleges; projects that are completely designed and need only to be built may be appropriate as projects for high school vocational programs.

Thus the idea of using students in the design and construction of assistive devices can be applied at various levels of the educational process.

FUNDING

When working with students on design projects, it is important to have funding for building the design before the design work begins. This gives students the sense that they are working on a real project and that they are going to have both the opportunity and responsibility to see it through to completion. It also gives students a definite budget within which they must develop their design, thereby providing a very tangible design constraint.

Establishing dollar amounts for the design projects also helps in determining which projects are appropriate for inclusion in the course. Our projects cost, on average, $500.00 for materials and labor. Since the labor comes largely from the students at no cost, most of the $500.00 is used for materials. We have found that a $500.00 project is about the right level of complexity for student engineers. If we had $5000.00 for a project, chances are good that the design would be beyond the abilities of the students, and that the time requirements would be excessive. Thus, when we are presented with a prospective project we consider, among other things, whether it is likely that the project can be constructed within our funding limit.

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Iconic Interfaces in Intelligent AAC Systems

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Abstract

The problems in developing a system with the complete linguistic ability of a human speaker are overwhelming given the current state of technology and linguistic theory. However, some of the issues involved can be finessed by providing the system with certain kinds of linguistic information. Using multi-meaning sequenced icons as an input medium allows the system to get much information out of few actuations. This paper discusses the use of such an interface in an intelligent AAC system.

Multi-Meaning Sequenced Icons

The ideal interface represents input selections transparently and has a relatively small number of input choices or keys. An interface intended for individuals who are cognitively or physically impaired must generate language with a low number of actuations. Letters have serious problems as input media because they require 6+ actuations per content word. AAC operators usually select one key every 5 to 8 seconds. Congenitally speech impaired people often have weak reading and spelling skills. As an alternative to letters, single meaning pictures have serious limitations, because hundreds of pictures are required to instantiate even the simplest vocabulary (with only one lexical item per picture).

A patented technique called *semantic compaction* approaches the problem of sentence generation by interpreting icons to have different meanings in different contexts (Baker, 82), (Baker, 84). This technique exploits the natural polysemy inherent in illustrations of real-life objects. For example, an apple is not only an apple, it is also red, a fruit, and round. When used in a sentence describing a favorite color, an apple icon can be interpreted as indicating the color red. In general, this approach allows operators to access a much larger number of concepts with the same number of input keys when multi-meaning icons are used in place of letters, words or single meaning pictures.

For both cognitively impaired and cognitively intact individuals, semantic compaction has been thoroughly explored using simple transducer programs to retrieve pre-stored language items when particular sequences of icons are actuated. For example, on a system designed for a cognitively intact operator, an average of 2 actuations is required to retrieve a word (3 or 4 actuations for a template sentence). Such a system supports a substantial (greater than 50%) reduction in the physical effort required for communication, using an input layout with fewer than 100 keys. The cognitive requirements are substantially reduced as well. This is a major improvement, but it is not enough. If the sentence to be generated has 8 words (not an unreasonable sentence length), then this type of system will still require 16 actuations to create it. If the operator needs 8 seconds for each actuation (which is the case for a large population of operators), then an 8 word sentence will still take roughly 128 seconds, or over two minutes.

Symbol Parsing

Existing AAC devices allow the operator to actuate certain choices or sequences of choices on an input device to retrieve pre-stored language items (single words or template sentences). While this is certainly useful, it does not help the cognitively impaired operator who does not have intact syntactic knowledge. The system will output only the words that are retrieved by the operator, in exactly the order that they are accessed, whether or not the resulting utterance is meaningful. This places most of the cognitive burden of communication on the operator, who must provide syntactic, stylistic and pragmatic information to produce an utterance. The pre-stored language items that are retrieved by the operator are generated by the device in the order that they are retrieved, even if that order does not produce a meaningful sentence. Systems that accept sequences of symbols or icons and produce words or sentences in the same order can be called *symbol parsing* or *transduction* systems.

Intelligent Word Parsing

It is becoming possible to develop more intelligent systems which take advantage of artificial intelligence and linguistic techniques to reduce the syntactic load and other cognitive burdens placed on the operator (Demasco et al., 89). The ideal system could require only the content words of an intended utterance and yet produce a syntactically and semantically well formed sentence. Such an intelligent parser has several tasks. Consider the input: *John go store yesterday.* The system must have semantic information about the individual words to determine that *go* is a verb, *John* is an agent of the action (since *go* must take an animate agent), *store* is the object (since physical locations are things that can be gone to), etc. (McCoy et al., 89a).

Once the semantic roles have been deduced, a natural language generation system could be used to fill in necessary syntactic information (e.g., determiners, prepositions, necessary verb inflections) to produce a sentence such as: *John went to the store yesterday*.(McCoy et al., 89b).

An intelligent *word parser* could lift much of the cognitive load from the operator since s/he would no longer be concerned with syntactic information. The system would be constrained to produce semantically and syntactically well-formed sentences.

Of course, the production of such utterances is not without a cost. The system requires large amounts of knowledge and powerful inferencing techniques in order to produce the utterances.

Icons and Intelligent Parsing

By combining a scaled-down version of an intelligent parser with multi-meaning sequenced icons, it is possible to make a usable, intelligent AAC system a reality. A well-chosen geographic layout can provide the system with syntactic and semantic information based on the locations of the icons that are selected, thus reducing on the knowledge and inferencing required by the intelligent parser.

While this layout strategy builds on the basic idea behind the Fitzgerald key (Musselwhite & St. Louis, 82), it differs in several important ways.

- The symbols in the proposed system are multi-meaning.
- The user need not select all of the words in the sentence to be generated -- the word parse is responsible for automatically adding function words that are required for purely syntactic reasons.
- The arrangement is actually helping the system (although it is likely to have benefits for language-impaired operators as well).

In representing a large vocabulary by combining icons together, the icons in three 8-icon columns can combine to produce 300 agents. Similarly, the same 24 icons can combine to produce 300 patients if the icons are situated in a different location to distinguish them from the agent icons. Two columns of 8 icons representing modifiers or function words can be placed at crucial parts of the board. The central notion behind this layout is that the icons can sequence to access a large number of unique strings. It is the multi-meaning nature of icons and their ability to form sequences that indicate a single notion which give them their combinatorial expressive power. If we were using single meaning pictures, we would only be able to represent 24 agents and 24 patients if we used the same layout. It is important to note that the usefulness of an intelligent system will be defeated if it makes use of a burdensome interface that places a high physical and/or cognitive load on the operator while placing severe restrictions on the depth of his/her vocabulary. For this reason, multi-meaning icons seem to be the most appropriate interface media for intelligent AAC systems.

Conclusion

We have described a method that synthesizes iconic interfaces with intelligent parsing. The result is a system which combines the advantages of both with minimal constraints. By keeping the vocabulary at approximately 1000 words, it is possible to implement this system on current generation hardware. The result would be an intelligent communication system useful to a large number of people with disabilities.

Acknowledgments

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COMMUNICATIONS AND CONTROL FOR THE SEVERELY DISABLED: THE SMARTLINK SYSTEM AND THE TONGUETOUCH™ KEYPAD

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ABSTRACT

The SmartLink System is a tongue activated intra-oral communications controller that permits people with quadriplegia or other severe disabilities to interact with computers, telephones, and home or office equipment. This product has been designed to utilize the tongue's sensitivity, quickness and spatial awareness in an innovative use of technology that offers significant advantages over existing controllers for the severely disabled.

PRODUCT DESCRIPTION

The SmartLink System is comprised of the TongueTouch Keypad, a SmartLink Controller, and various SmartLink Modules connecting the system to external applications.

The TongueTouch Keypad is a battery operated, radio frequency transmitting device which is similar in appearance to an ordinary orthodontic retainer and includes a keyboard with nine tongue activated keys. (See **Figure 1**) It is customized to each individual and fits against the roof of the mouth in a comfortable and unobtrusive way. Small, pressure-sensitive keys are pressed by the tongue to control external equipment. The unit is made from bio-compatible materials and may be worn at all times except during dental hygiene and meals.

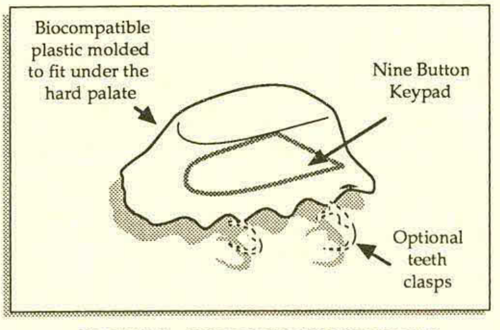

FIGURE 1: TONGUETOUCH KEYPAD

The SmartLink Controller sits near the bed or is attached to the user's wheelchair, and is connected via a cable or a wireless transmitter to external equipment. (See **Figure 2**) The controller receives signals from the TongueTouch Keypad and processes the information using a microprocessor. A small display shows the system status and other information which is helpful to the user operating the system. Programs in the controller generate signals required to control a variety of applications through the specific SmartLink Modules.

SmartLink Modules are adapters for use with the SmartLink System applications. The system is designed to control applications such as a nurse call switch, motorized bed, lights and appliances, remote control consumer electronics, a telephone, a computer, and a powered wheelchair.

Among the estimated 7.9 million mobility-impaired persons in the U.S., Canada, Western Europe, Australia and Japan, the majority of individuals who can benefit from the Company's products may be grouped into one of four classes of disability: [1]

1. **Quadriplegia due to Spinal Cord Injury;**
2. **Quadriplegia due to Other Causes** (includes Multiple Sclerosis, Muscular Dystrophy, Stroke and Head Trauma);
3. **Paraplegia;**
4. **Hemiplegia.**

An important characteristic of all these pathologies is that tongue function usually remains intact and available as a potential means of control after limb control has been lost. In almost all instances, traumatic, disabling physical injuries do not affect tongue function due to the cranial innervation of these muscles. In neuromuscular diseases such as multiple sclerosis, tongue function typically remains intact after limb control has deteriorated.[2,3]

METHODS OF PRODUCT EVALUATION

Currently product development is focused upon evaluation of product performance and user acceptance. Assessment of performance involves objective, quantifiable parameters that are measured using *Model Based Tasks*, *Partial Tasks*, and *Whole Tasks*. The evaluation of user acceptance involves measures of subjective parameters covering topics such as ease-of-use, aesthetics, and user satisfaction.

Model Based Tasks use standard communications theory and human factors models to quantify system performance parameters. These models provide methods to determine the ultimate information capacity, or equivalently, the maximum information transfer rate of the communications interface.

The information transfer rate can be quantified with the equation below:[4]

$$I = (1/t)\ \mathrm{Log}_2 N$$

where I = information data rate;
t = time required for one key to be pressed and decoded;
N = number of unique keys.

The advantage of the TongueTouch keypad over commonly used input devices lies in the larger value of N. While a single switch device has $N = 2$ (presence and absence of switch), the TongueTouch Keypad with 9 switches has $N = 10$. Assuming the variable t is constant, the greater number of switches results in over three times the information capacity when using the TongueTouch Keypad versus single switch input devices.

Partial Tasks focus on the elements of complete system operation. Tasks such as character input on a personal computer, dialing a single number on the telephone or switching on the lights are basic elements of SmartLink System applications. Problems or difficulties with these functions would limit *Whole Task* performance. Quantifiable measures of performance such as time to complete the task and error rate are most readily measured by partial tasks.

Whole Tasks assess the complete system performance. The desire to provide maximum user self sufficiency is of particular concern along with identifying and measuring the system's functionality. Whole task activities might include writing a business letter on a computer, completing a personal phone call, or controlling one's personal environment throughout the day.

Methods to assess subjective parameters such as ease-of-use, aesthetics, and user satisfaction include surveys, suggestions, and comments or concerns brought up by the subjects and staff prior to and during clinical testing.

PRELIMINARY RESULTS OF CLINICAL TESTING

Two C-5 subjects with quadriplegia due to traumatic spinal cord injury were fitted with TongueTouch Keypads. The application selected for this initial testing was control of an Apple Macintosh personal computer through "mouse" emulation.

The *Partial Task* selected for quantitative evaluation was character input. The results averaged 28 characters per minute for the numerals 1 to 10, 18 characters per minute for the alphabet A to Z. The *Whole Task* of typing a 40 character sentence averaged 12 characters per minute. These preliminary results involved first time use of the SmartLink System and the Apple Macintosh Computer. These data rates were also influenced by the use of a keyboard emulator program that has not yet been optimized for the nine key SmartLink System.

Qualitative feedback from the users provided valuable design recommendations such as further reducing the thickness of the TongueTouch Keypad so that the user was less self-conscious during speech and swallowing was more comfortable. During the two day extended-wear field tests the device became less noticeable and remained stable and in place during all activities. Also, information data rate was found to be lower than preferred, even though higher than some other input devices. Among the features most liked by the subjects were the "invisibility," stability, and ease of inserting and removing the TongueTouch Keypad.

CONCLUSION

The potential benefits of the SmartLink System to the disabled user are decreased need for attendant care, greater personal independence, increased use of cognitive resources, greater opportunity for gainful employment, and enhanced personal safety through improved control capabilities. Additional product developments addressing the valuable feedback received in clinical testing must be performed to insure the production of a high performance, user accepted device.

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Clinical testing was conducted at the VA-Palo Alto Spinal Cord Injury Center.

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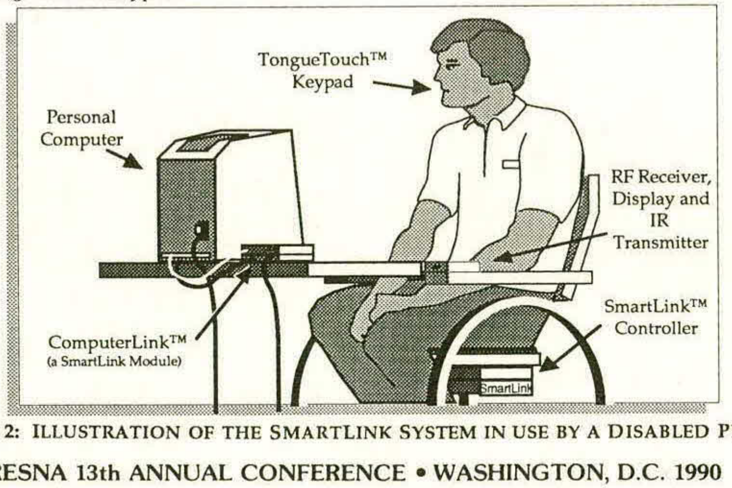

FIGURE 2: ILLUSTRATION OF THE SMARTLINK SYSTEM IN USE BY A DISABLED PERSON

Connecting Peripherals to AAC Systems through a Common Communication Bus

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Abstract

One of the more frustrating aspects of working with augmentative and alternative communication (AAC) systems is the difficulty of interfacing to other devices and peripherals. Whether interfacing to simple switches or computers, compatibility is often an issue. We have investigated a communication link that simplifies such an interface. The link is based on the I^2C protocol and has been designed to address compatibility, cost and flexibility considerations for AAC systems.

Background

The ability to connect to computers and various other devices in an individual's environment has been noted as one of the requirements for communication systems (Vanderheiden and Lloyd, 1986). In practical terms, however, connecting to peripheral devices has always presented challenges to developers of AAC devices. Standardization in various areas has helped reduce compatibility issues. Serial data transmission has been standardized by the RS-232 protocol. The SET standard set forth by the Trace Center has simplified making devices compatible with a wide number of switches. The CEBus holds promise for standardizing interfaces between consumer products.

However, there is still no common link between the different types of devices. For example, making a communication aid compatible with simple switches, joysticks, computers, the Unicorn keyboard, printers and the CEBus requires a number of connectors and circuitry to support the devices. Furthermore, many operators do not need to connect to all the peripherals with which a device is capable of interfacing. For this reason, manufacturers of AAC systems prefer not to add the expense of interfacing hardware that is not needed by the operator.

A study funded by the National Science Foundation (Romich, 1984) determined that a common bus approach for connecting diverse components of a system was feasible, although the specific bus architecture was not specified. Our goal was to develop a communications bus that forms a common link between the various types of devices, making them simpler to use and to understand for the operator or clinician and eliminating unnecessary interface hardware.

I^2C description

I^2C (Inter Integrated Circuit) is a serial data transfer method introduced and supported by Signetics. It is a multi-master bus capable of a transmission rate of 100 kilobits/second. We chose to use the I^2C method for several reasons:

1 - The bus can be daisy-chained; thus limiting the cables needed to connect peripherals.

2 - Since any device on the bus can be a master, the main processor does not need to poll or monitor each device on the bus.

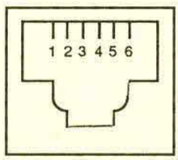
3 - Signetics makes a number of special function chips which have the I^2C hardware on board.

4 - The I^2C hardware monitors bus contention. When two or more devices attempt to drive the bus at the same time, one device assumes priority while the other device waits to re-transmit when the bus is free.

5 - During any transmission, either the master or slave can slow down the transmission rate on a bit by bit basis when either has additional processing requirements.

6 - The cost of wires and connectors can be kept to a minimum since I^2C needs only 4 conductors: data, clock, power and ground. (Note: although the I^2C protocol does not specify a power conductor, we used it because it allows the host to provide power to peripherals.) Modular phone wires and connectors were used because of their durability, low cost and availability. Figure 1 shows the connector and pin-out used in our implementation.

Jack Type:
USOC RJ11



1 - NC
2 - Data
3 - Common
4 - +5 VDC
5 - Clock
6 - NC

Figure 1: pin-outs of I^2C jack

Device Addresses

I^2C allows for 127 unique 1-byte addresses on the bus. With additional decoding an address can be any length, but for speed considerations, it is preferable to keep the addresses (and thus the transmissions) as short as possible. An additional addressing consideration is that each device on the bus needs to be seen as a separate entity. For this reason, two identical devices (such as two similar switches) must have unique identification numbers.

A popular method for producing IDs is to use randomly generated identification numbers where duplicate IDs are resolved during bus collision. This method, however, has problems in keeping track of identical but separate peripherals. The address assigning method that we have chosen is to program a serial number into each peripheral's EPROM. The device address identifies the type of device (keyboard, joystick, printer, etc) as well as a unique serial number. This ID can contain up to six bytes. As mentioned earlier, it is desirable to keep the ID number as short as possible. For this reason, the designated host of the bus can monitor the devices on the bus and assign each a unique one-byte ID that is used in subsequent communication.

Verification of Transmission

Another advantage of I^2C communication is that each byte is acknowledged by the receiving device. In each message that we send on the bus, the second byte indicates the number of bytes in the message. By comparing this byte to the number of bytes acknowledged, both the sender and receiver of the message have an indication of whether the transmission was successful. If not, the receiver can ignore the failed message and the sender can re-transmit.

Data Format

Since data to be transferred by each type of peripheral can differ greatly, the data format from one device to the next can also vary. In the initial communication on the bus, a peripheral identifies itself and specifies which type of device it is. The host then knows the type of transmitting device and its expected data format. The one-byte ID is only assigned after the device type and data format are known. The host device must either know the data format for each type of device that can be plugged onto the bus, or a method must be used to specify the data format when the peripheral identifies itself.

Transmission Messages

Information is sent between devices on the bus in 'messages.' Each message consists of: destination address, source address and data. In addition, the second byte in the message indicates the total number of bytes in the message. The destination address specifies the device for which the message is intended. The source address specifies which device is transmitting the message. The host can respond to messages it receives based on the type of device that is sending the message. Not only can the host interpret data from the keyboard as key closures while interpreting similar data from a computer as ASCII data, but it also allows the device to respond differently to data coming from similar devices. For example, four similar switches could be daisy-chained to a communication device and used for directed scanning.

Connecting to Non-I^2C Devices

Many of the peripherals that can be used with an AAC system do not currently use our I^2C protocol. For these cases, we have chosen to make adapters that convert between I^2C and the peripheral's format. For example, an RS-232 device can be connected to the I^2C bus by an I^2C to RS-232 adapter. At first this may seem like an unnecessary extra step in the development; one serial protocol is converted to another and then sent to the host device. However, this method has some attractive benefits. First, the RS-232 interface hardware is only purchased if the consumer wishes to connect to such a device. Secondly, the operator is not limited to the number of connectors that the manufacturer chooses to put on the system. The operator can set up as many RS-232 ports as are needed.

For future expansion, an additional consideration for greater flexibility is to put the I^2C decoding software into EEPROM. This allows the capabilities of the AAC system to be expanded to maintain compatibility with new peripherals and new I^2C data formats by updating its decoding software to communicate with the new peripheral. With EEPROMs, the program could be updated through a communication link such as a modem. In this way, device compatibility can be maintained and expanded without opening a device - no hardware changes are required.

Conclusions

We have been developing and testing this I^2C method of connecting devices for approximately eight months. At the time of this writing we do not havę a complete system with a full line of peripherals, but our initial results show promise. The host and peripherals communicate with each other with the addresses indicating which devices should receive the message, which device is sending the message and how the message should be interpreted. We have found it difficult to maintain a transmission rate of 100kbits per second because of the software overhead that is involved. A slightly slower rate seems to pose no problems; the bus is still fast enough to handle the data that needs to pass between devices. We believe that this I^2C communication protocol could make AAC systems more flexible and help solve compatibility problems between devices and peripherals.

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DEVELOPMENTS TOWARDS AN INTEGRATED PROSTHESIS FOR THE NON-VOCAL

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ABSTRACT

The development of communication systems for the non-vocal is a complex task, and a number of different computational techniques need to be used within such a system. A linked set of projects aimed at this objective are described. This paper describes the integrated strategy adopted in the research and shows the inter-relationship between the various projects.

INTRODUCTION - A COMPLEX TASK

Human communication using speech is conducted in a wide range of styles and follows a variety of complex and subtle rules.

These rules cover not only vocabulary and syntax and semantics, but also pragmatic rules which determine, for example, whether a particular interjection is considered appropriate by the listener, achieves the objective of the speaker, and obeys the particular rules of social behaviour which apply to the particular context of the conversation. Many of the rules governing speech communication, particularly the higher level semantic and pragmatic rules, are very poorly understood.

The designers of communication systems for the non-vocal thus have particularly difficult problems in trying to provide technological alternatives to natural speech (1).

The fundamental problem is that of providing a means of controlling an output device, such as a speech synthesizer, on the basis of the very limited information transmission capacity of a non-vocal person. The complexity of the system which is to be simulated, however, and the wide variety of abilities of non-vocal people mean that the problem is far from simple.

A UNIFIED RESEARCH STRATEGY

It is unlikely that a single technique will be adequate for all the communication requirements of even one individual user, but it is also unreasonable to expect a person to have to use a number of completely separate systems. Therefore our research strategy is to have a number of research and development projects which, although having individual goals and resources and being at different developmental stages, are interlinked and have a unified overall objective. The various projects which form this strategy and the concepts linking them are shown in Figure 1.

AN INTEGRATED PROSTHESIS

The long-term objective is the development of an integrated prosthesis which is appropriate to the four different communication situations listed in Blocks A to D in the centre of figure 1. The system would be designed so that the user could move between these different modes of communication in an efficient and effective manner.

The Blocks A to D correspond to four individual projects. The "PAL" system for unique utterances is now well established and also has been integrated into a prototype "CHAT" system for user trials of this particular combination. "TOPIC" and "TALKBACK" are at an earlier stage of development.

The work focussed on the development of prostheses is supported by a number of research projects (Blocks E to F). When they are at an appropriate stage of development, the techniques developed in these projects are transferred to the Integrated Prosthesis development.

OTHER APPLICATION AREAS

During our research for the non-vocal it became clear that some of our systems, particularly the predictive ones, could have much wider application. We thus instituted the three further development projects (Blocks I to K) shown on the right of figure 1.

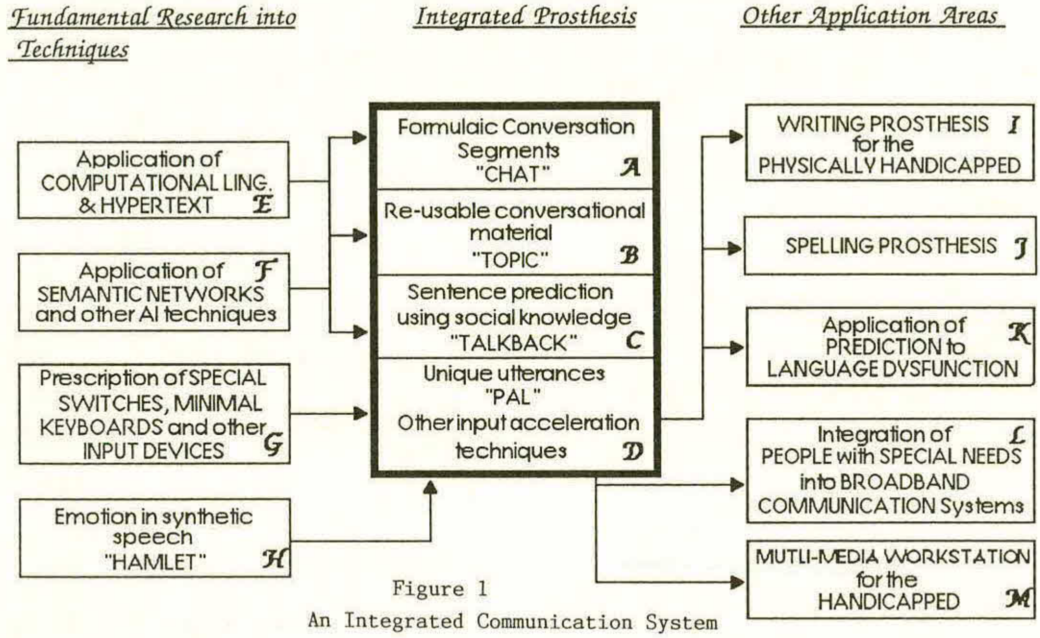

Figure 1
An Integrated Communication System

In addition, we applied the concept of an integrated prosthesis to Broadband Communication systems within a European wide collaborative project (Block L), and also obtained research council funding for a multi-media workstation for the handicapped (Block M). The particular focus of this project is the use of state-of-the-art workstation technology, and the concept that human-interface systems developed for the disabled can be efficient for the able-bodied in certain important situations.

Results from and description of each of the individual projects listed above have been and will be presented separately (see references A to M).

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AUTOMATIC DATA COLLECTION AND ANALYSIS IN AN AUGMENTATIVE COMMUNICATION SYSTEM

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ABSTRACT

A technique has been developed to provide quantitative feedback on the use of augmentative communication systems. The technique involves two steps: data collection and data analysis. Data collection is automatic and occurs whenever the system is in use. Each selection made by the user, as well as the time taken to make that selection, is recorded in a data file. At any time, this file can be analyzed to gain information about system use and the efficiency of the current system configuration. At this time, the technique is being used with a software based system, named Meta4, which is under development. Clinical evaluation of the system will further indicate what information from the analysis is most helpful in order to optimize a particular configuration.

INTRODUCTION

The programmability of augmentative communication (AAC) devices has made it possible to configure a system for a specific user. In most cases, this means that the system can be continually updated to account for changes in a user's needs. However, more quantitative information is needed in order to determine what changes should be made to improve system acceptance and function (2,3). One approach is the real-time recording of data by the device as it is used. This technique has been used in other areas of research, e.g., to monitor wheelchair function or physiological events (4-6), but has not yet been explored for AAC applications. To examine the effectiveness of this method for augmentative communication, a feature called "usage tracking" has been incorporated into a system called Meta4. This feature allows system use to be constantly monitored and analyzed. Based on this analysis, suggestions can be made on improvements to the current setup based on quantitative information.

BACKGROUND

Meta4 is a software based augmentative communication system currently under development. The distinguishing feature of this system is the degree of flexibility of the vocabulary set and many of the system parameters (1). The system is also very modular making it easy to add components or features at a later time. It is this extensibility that has allowed the addition of the usage tracking feature.

Meta4 operates by displaying one screenful of information at any given time. This block of information is called a "page". A user's vocabulary set is comprised of any number of these pages and is called a "book". On each page is a row/column display of items, e.g. letters, words, or phrases, that the user can select. Movement between pages is achieved by selecting an item with a "change page" function attached to it. This is all easily programmable by the user or clinician. In order to produce a message to speak or print, a user moves between the pages selecting the various components of the message. When the message is complete, a "speak" or "print" item can be selected to communicate the message to others.

METHODS

Data Collection

The process of data collection involves the recording of every selection made by a user and the time that the selection was made. The data file storing this information is opened when the system is turned on and the date of the recording is written to that file. As the system is used, selections are stored and periodically written to the file. Although a minor delay may be detected during the writing process, the constant updates to the file prevent information from being lost should someone turn off the device without exiting the program.

Data Analysis

An analysis utility has been written which transforms the raw information from the data file into useful information about system use. Suggestions on possible system changes are also made based on the results of the analysis. Typical information provided by the utility includes the following:

- frequency of use of a selection with respect to selections on the page
- frequency of use of a selection with respect to the entire vocabulary set
- frequency of use of each page
- time taken for each selection
- time taken to spell out words and the number of times a word was spelled
- average communication rate

Using this information, the analysis utility can provide more practical feedback. This information can then be used, if desired, to make changes to the system. Typical observations might include:

- the device is used frequently/infrequently
- a word stored in the vocabulary is being spelled out
- a word not in the vocabulary is used frequently
- a page/selection is never used
- there are long pauses between selections
- phrases stored in abbreviation/expansion lists are being spelled out
- abbreviations are never being used
- certain phrases are spelled out frequently

DISCUSSION

The usage tracking feature is designed to provide quantitative feedback about the use of an augmentative communication system. Incorporated into that design is the belief that the user or clinician is in the best position to decide exactly what changes are actually made to the system. Therefore, the usage tracking feature only *suggests* changes based on the data and leaves it up to the person configuring the system to decide if or when those changes are incorporated. This avoids the possibility that an automatic change may actually cause efficiency to decrease (as might be the case if some visual or perceptual problems exist).

In addition to using the usage tracking feature for changing the system configuration, it can also function as an evaluation/assessment tool. For example, the effect of changes to the system can be monitored. This may include:

- changes over time
- changes with new input devices or methods
- changes due to a new configuration
- changes due to a new vocabulary arrangement

Since any change may result in a temporary decrease in efficiency, the usage tracking feature can help detect how long that decrease lasts and which changes appear to disrupt function the most.

Meta4, with the data collection and analysis capabilities, is scheduled to be clinically tested in the near future. The results of these tests will indicate what information is the most helpful to record and which types of analysis provide the most useful feedback. As part of the evaluation, the usage tracking feature will also be used to assess the effects of system changes on performance.

ACKNOWLEDGEMENTS

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A Human Factors Approach to Vocabulary Management for an Augmentative Communication Device

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Introduction

Since the conditions contributing to an inability to communicate are usually chronic ones, augmentative communication use is typically long-term. Over time, systems need to be modified to keep pace with changes in user abilities and life-style (2). Although software based augmentative communications devices are designed to allow for a changing vocabulary, they still require a significant customizing effort (1,4). At the current time, the process of setting up a system with robust capabilities is long, arduous, and largely manual. An obvious need exists for a vocabulary management tool. A menu-driven vocabulary modification tool provides a means of managing a flexible, hierarchical vocabulary. In order to be an effective tool though, it must perform the assigned task and it must be easy to use. To that end, a human factors approach that emphasizes the needs and expectations of the target tool user (6,7) is in order. One such approach is taken by the vocabulary management tool (VMT) for Meta4, an augmentative communication system. It incorporates a detailed profile of the user alongside the functional specifications.

Design Approach

Typically, a software engineering effort takes a top-down approach. To illustrate, this paper focuses on the development of a multilevel user profile (i.e., a formal description of the user) and considers portions of the VMT user profile. The profile is written on three levels of abstraction, the user, system, and utility levels, and is based on a few design conventions:

1. Note that the computer is just one part of the software system. The person using the computer is the other essential part (5).
2. Base the design on things that are familiar to the user. Make all unfamiliar aspects of the system eminently logical to the user (3).
3. Design operational features of the system around the user's expectations (3).
4. Allow the user to concentrate on the task at hand rather than on how to use the tool. Let the user accomplish the job with as little fuss as possible (3).
5. Provide for the novice and allow for user growth (6).
6. Simplify *all* aspects of the system.

For this examination, it is assumed that a requirements document exists for the vocabulary tool and that it contains an outline of the tool's functional capabilities (including adding, deleting, modifying, and moving an individual vocabulary word, symbol, or abbreviation.)

The profile begins by identifying the intended user of the tool and detailing his/her characteristics. This delineation constitutes the user level abstraction, which is the highest level of abstraction in profiling the user. It initiates the application of the first design convention. An excerpt of the VMT user profile includes:

> In most cases, the user of the vocabulary modification tool will be a care-giver or a clinician. On less frequent occasions, the vocabulary tool user will also be the augmentative communications device user. Our design will need to be flexible enough to accommodate the physical, visual, and perceptual needs of that person. The vocabulary tool user will be a reader/speller whose cognitive capabilities will be at least of fourth grade level. The user's confidence in, understanding of, and experience with computers and interface utilities will cover a wide range. We must accommodate even the novice computer user.

The profile continues with the system level abstraction, which pertains to the manner in which the user intends to use the major components of the system. The system level abstraction has two parts. First, a narrative models the behavior of the user at the main menu of the interface. It can be a sequence of events that describe a sample session. It can also include the circumstances related to using a major component of the system. The VMT user profile contains a detailed portrait of three editing styles, and then identifies when and how each style is applied in modifying the vocabulary structure. A condensed narrative of one of the editing styles includes:

> This section of the profile addresses user activities for page modification sessions. Page modification (i.e., application of one or more editing operations to a given page/screen of items) is likely to occur at an intermediate stage of vocabulary development or when a page needs to be rearranged. The user is likely to know or recognize the name of the target vocabulary page

or how to navigate to the target page. Once the user has reached the target page, s/he will execute one or more editing operations. The user might want to edit another page or s/he might prefer to initiate another editing style at any point in the editing process.

The second part of the system level abstraction is a list of user expectations. The list identifies attributes related to the narrative. Examples of user expectations might include:

1. The user will want the system to have a readily modifiable set of default behavior parameters.
2. The user will want to be able to apply a series of editing operations to a designated page.
3. The user will want to see the vocabulary layout while s/he is modifying it.

The third, and lowest, level of abstraction of the user profile is the utility level. It treats the details pertaining to subcomponents or utilities of the system. Like the system level abstraction, the utility level contains a narrative as well as a list of expectations. For example, the following excerpt describes the process of specifying a page name:

To specify a page of vocabulary items, the user might want to have several methods available. If the user knows the name of the page, s/he might want to highlight this name in an ordered (hierarchical, alphabetical, user specified) list of page names or s/he might want to enter the name manually. In lieu of entering an exact page name, the user might prefer to invoke pattern matching or completion capabilities.

A portion of the VMT list of attributes for entering a page name includes:

1. The user will want be able to use his/her normal input device (e.g., switches, arrow keys, joystick, keyboard) and input method (automatic scanning, directed scanning) to select from a list of page names.
2. The user will want the capability to move to adjacent pages in the vocabulary hierarchy.
3. The user will want to select the ordering for the list of page names.

Once the profile is complete, it is possible to begin the formal system design. The design fulfills the requirements and incorporates the profile in accordance with the design conventions. For instance, the Meta4 VMT interface display strives for visual and functional familiarity by using drop-down menus. The system is simplified by presenting a single level of menu choices rather than hierarchical or nested menu choices. It responds to expectations and it allows for growth by permitting the user to set system control parameters. The VMT's simplified input format allows the user to concentrate on entering information rather than on an enforced sequence of operations.

Meta4 provides the framework for an adaptable communication device. The VMT allows the user to take full advantage of Meta4's potential for customization. It will allow the user to rapidly construct an initial vocabulary set. It will reduce the time and effort involved with vocabulary updates. It presents one solution for managing long-term communication needs.

Acknowledgments

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PRESCRIBING CUSTOMIZED CONTOURED SEAT CUSHIONS BY COMPUTER-AIDED SHAPE SENSING

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INTRODUCTION

A new Computer-Aided Shape Sensing System (CASSS) has undergone the initial investigation for its clinical implementation. Ultimately, this will include such populations as the spinal cord injured, those with cerebral palsy, the elderly and others. Factors such as sex, weight and disability will also be considered. The CASSS utilizes spring stiffness and preload to determine contour and force profiles. The primary goals of the study were to determine an appropriate spring for the supporting media and to correlate the spring stiffness with the stiffness and thickness of polyurethane foams; materials which are both useful and inexpensive. In this way, the CASSS will provide a quick effective method for prescribing custom contoured cushions to address a variety of seating needs.

METHODS

Initially, three music wire springs with diameters 0.033", 0.035" and 0.037" of varying lengths were designed. Vibration and load-deflection testing was conducted on the CASSS to determine the optimal spring corresponding to an existing foam contoured system.(1) A seven inch long, 0.035" diameter spring was then selected. The characteristic linear equation of the CASSS, $F = K*X + (F1 + 0.96*K(V - 2.5))$, was then used to determine the appropriate spring tension in terms of voltage.(1) Here, F is the force measured, K the spring constant, F1 the preload associated with the spring and V the voltage related to spring tension.

Based on previous experiences with cushion testing and clinical studies, three foams of varying stiffness, HR-32, HR-45 and HR-55 were chosen.(2) The ASTM Standard ILD test was conducted for each cushion at 2",3" and 4" thicknesses. Based on this data, we would like to be able to prescribe custom contoured cushions while utilizing both the contour and force distribution data provided by the CASSS. Using a previously existing CAD system, which measures cushion deflection contours at the buttocks-cushion interface, the 3" foams were tested with able-bodied subjects. The deflection data obtained was then used to approximate the corresponding voltage determining spring tension in the CASSS. This enabled us to predict the spring tension corresponding to a particular foam stiffness.

After the voltages for the three foams were determined, eight able-bodied subjects were tested. The first phase of the testing involved obtaining deflection measurements from the passive system on each of the nine foams. The second phase involved obtaining both deflection and force measurements from the CASSS. For a particular cushion stiffness, the tension of each spring was determined by setting the individual voltages to the previously determined values.

RESULTS

For the 0.035" diameter spring selected, the relationship between the spring tension of the CASSS, in terms of voltage, to a particular cushion stiffness with a 3" thickness is as follows:

cushion stiffness	voltage (spring tension)
HR-32	2.0 v
HR-45	3.0 v
HR-55	3.7 v

These relationships were validated by the subject testing of eight able-bodied individuals (five males, three females). Figure 1 illustrates the correlation between the deflection measurements (seat contour) of a normal male on a 3" HR-45 cushion obtained from the passive system and the deflection measurements for the same subject associated with a voltage setting of 3.0v obtained from the CASSS. Both the quantitative and qualitative results for each cushion stiffness with corresponding CASSS voltage were similar.

(a)

Contour (mm)

0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	8	16	19	18	16	8	0	0	0
0	0	3	18	25	28	24	24	20	8	0	0
0	0	8	22	31	28	25	28	24	12	0	0
0	0	10	22	30	24	17	23	21	11	0	0
0	0	14	19	23	18	4	13	15	11	1	0
0	0	10	16	16	9	0	6	11	10	1	0
0	0	10	14	12	1	0	3	7	7	2	0
0	0	12	15	11	0	0	0	6	8	2	0
0	0	15	16	12	0	0	0	6	10	7	0
0	3	18	22	11	0	0	0	12	15	17	0

(b)

0	0	2	5	5	2	0	0
0	5	20	23	23	21	8	0
1	15	31	29	29	29	17	1
1	16	29	28	23	27	15	1
1	13	23	16	12	19	19	0
1	10	13	4	1	11	11	1
2	10	11	0	0	6	12	2
3	11	11	0	0	6	11	7

Figure 1
(a) deflection measurements (mm) for an able-bodied male from the CASSS
(b) deflection measurements (mm) from the passive system

These voltages, however, only correspond to cushion stiffness at a 3" thickness. Therefore, we have developed an extrapolating technique to address situations where a 2" or 4" cushion is warranted. Figure 2 shows the load-deflection relationships corresponding to each thickness for a particular cushion stiffness. Here, an exponential best fit line was determined for each curve. For a 3" cushion, the optimal contour can be obtained directly from the CASSS. If a 2" or 4" cushion is needed, the force and deflection information will be used to extrapolate the demanded contour. The results obtained from this approach were consistent with those from the passive system.

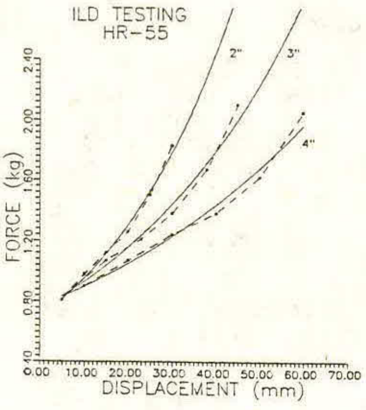

Figure 2. Load-Deflection Relationship for HR-55

DISCUSSION

The CASSS, in conjunction with the ILD data, provides a simple method for prescribing a custom contoured cushion. In addition to supplying the contour data quantitatively and qualitatively similar to that from the passive system, it provides force distributions essential for the prescription. In this way, the system allows for the assessment of a variety of seating needs for varied disabled populations. Further studies will be conducted to address these clinical evaluations.

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THE RELATIONSHIP BETWEEN SEAT ANGLE AND SPINAL EXTENSION IN PATIENTS WITH OSTEOPOROSIS

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INTRODUCTION

Osteoporosis is defined as an age-related disorder characterized by decreased bone mass and increased susceptibility to fractures. The decline in bone mass may start as early as 35 years of age, with a loss of 6% to 8% of total bone mass per decade thereafter. The loss of bone mass results in a proportional decrease of compressive bone strength. Many patients experience considerable discomfort while seated. In addition, the classic slouching posture of the osteoporotic patient results in unbalanced loading of the spine with greater pressure on the anterior aspects of the vertebral bodies. Ultimately a crush fracture will occur with the resulting wedging of the vertebral bodies. Changing the posture by extension of the spine could shift the pressure to the posterior aspects of the vertebral bodies and protect the anterior aspects from crush fractures. Clinical observations indicate that spinal extension reduces the level of pain experienced by the patient. A pilot study has been conducted to investigate the relationship between seat angle and spinal extension in patients with osteoporosis. The hypothesis is that significant extension of the spine can be accomplished in osteoporotic patients by increasing the angle of the seat and thereby increasing anterior pelvic tilt.

METHODS

The subjects for the study consisted of nine female patients diagnosed with osteoporosis. The patients were placed in a Balans chair which had been modified to allow a range of seat angles from 0 to 30 degrees. Reflective markers were placed on the forehead, chin, C7, T6, L1, sacrum, anterior superior iliac spine (ASIS), trochanter, femoral condyle, and seat. Figure 1 shows the respective positions of the markers. A video tracking system was used to record the position of the markers. Two calibration samples were recorded: one with the patient standing, and one with the patient seated at a neutral angle. Then three samples were taken at seat angles of 0, 5, 10, 15, 20, 25 and 30 degrees. Segment length and angle information were determined through software analysis of the video data. Of interest to this study were the angle between the T6-C7 segment and vertical, and the angle between the L1-S segment and the T6-L1 segment. Figure 2 depicts the angle between T6-C7 and vertical. Figure 3 depicts the angle between segments T6-L1 and L1-S.

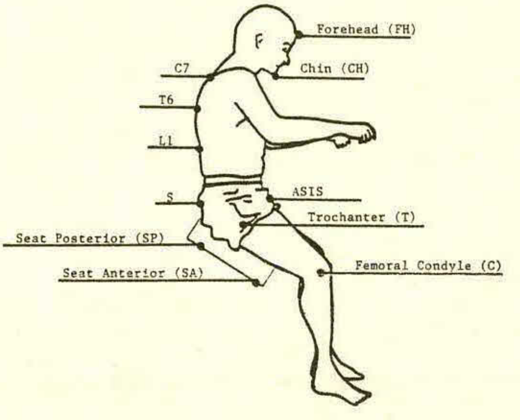

Figure 1: Marker Positions

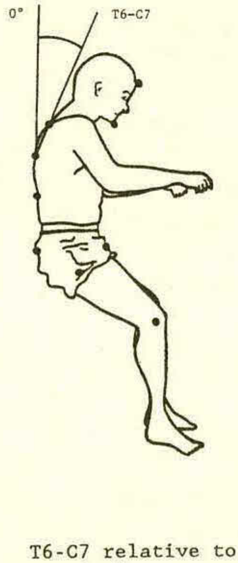

Figure 2: T6-C7 relative to Vertical

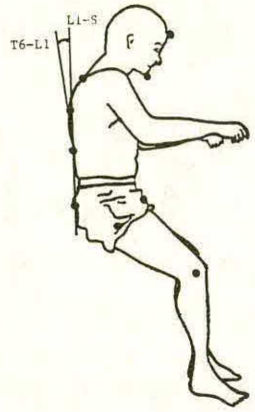

Figure 3: T6-L1 relative to L1-S

RESULTS

The three trials per seat angle were averaged for each patient. A linear regression was performed on these averages for each group of variables versus measured seat angle. Regression of the T6-C7 angle and seat angle resulted in a regression equation of: Y=7.5762-0.1374*X and a standard error of 0.0504. Regression of the angle between the T6-L1 and L1-S segments and seat angle resulted in a regression equation of: Y=12.8161-0.1692 with a standard error of 0.1079. Figures 4 and 5 show the relationships between the respective angles. While neither regression was statistically significant it is apparent from that the data that both spine angles decrease as the seat angle increases.

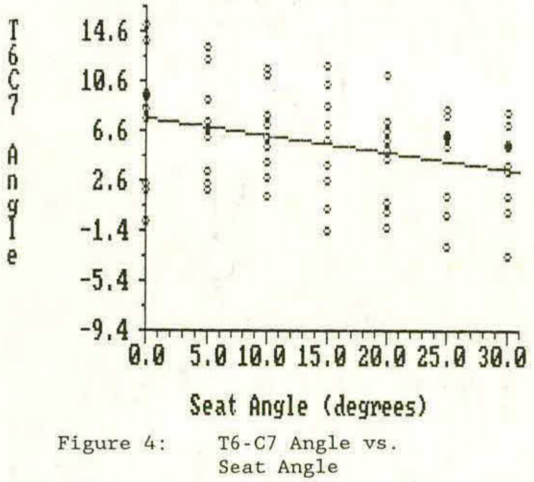

Figure 4: T6-C7 Angle vs. Seat Angle

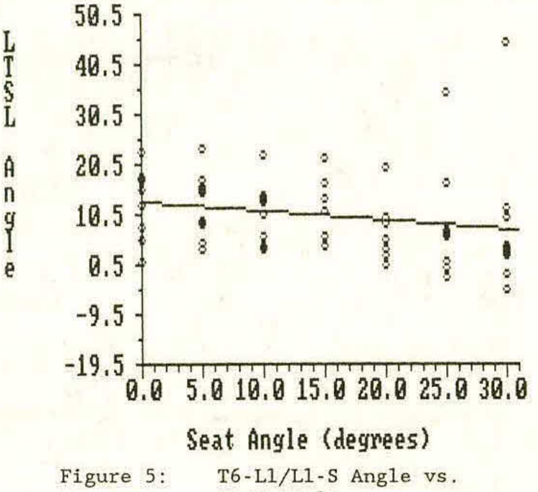

Figure 5: T6-L1/L1-S Angle vs. Seat Angle

CONCLUSION

Initial results indicate a relationship between seat angle and spinal extension. Analysis of the angle between spinal segment L1-T6 and segment L1-Sacrum shows that there is an increase in lordosis as anterior pelvic tilt is increased. The angle between the spinal segment T6-C7 and vertical decreases as seat angle increases indicating a reduction of kyphosis. Preliminary analysis supports the stated hypothesis: The increase of the lordosis and the decrease of kyphosis indicate an increase in spinal extension as the seat angle and anterior pelvic tilt are increased.

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Wheelchair Sitting Forces

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ABSTRACT

A force plate mounted on the seat of a wheelchair was used to measure the sitting forces and behavior while able-bodied, and spinal cord injured subjects sat for 30 min. intervals on ROHO and Jay cushions. The able-bodied also sitting on a hard surface. Normal and shear seat forces, the location of the center of mass, and armrest forces were measured. A larger percentage of the body weight, a larger average forward shear force and a more anterior position of the center of mass was observed with the ROHO cushion. More frequent and larger shifts of weight occurred with the Jay cushion. The armrests tended to support 5% of the body weight for quadriplegics compared to approximately 9% for paraplegics and able bodied.

Introduction

The long-term sitting pattern in spinal cord injured individuals may give clues as to why some get ulcers and others do not(1,2). There is evidence that paraplegics generate more seating shear than able-bodied individuals(3) and that the frequency and intensity of weight displacements correlate with subjective seating comfort(4). This study investigates the above mentioned factors.

Methods

Experiments were conducted on an E and J Premier wheelchair with the feet elevated to make the thighs level. An AMTI (AMTI, 141 California St., Newton, MA 02158) force platform (40.5 cm x 40.5 cm x 4.45 cm) replaced the standard wheelchair seat, measuring normal and shear force, and the moments around the axes. The moment was divided by the normal force to determine the anterior-posterior (A-P) and lateral positions of the center of normal sitting force.

The force platform, as purchased, did not give the correct normal force readings along its edges. This was remedied by attaching a 3 mm thick plastic sheet cut back 4 cm from the edge of the platform to the platform surface followed by a 3 mm thick metal plate with the same size as the platform fastened on top. With the modification, normal forces applied to the edges of the platform are less than 5% different from center force mesurements.

Six able-bodied (avg. wt. 76 kg), six paraplegics (avg. wt. 83 kg) and five quadriplegics (avg. wt. 66 kg). The spinal cord injured had complete sensory loss below the waist.

A control recording was first made with the arms off the armrest to determine the amount of weight supported by the arms during the long data collection period. The subjects were instructed to sit normally for 30 min. The spinal cord injured subjects sat on ROHO and Jay cushions, while the able-bodied subjects also sat directly on the force plate.

The normal force readings were standardized to percent body weight. The standard deviation of the force parameters was used as an indication of activity level. As an indicator of lateral weight shift, a count was calculated of times that the weight shifted across the average position of a subject using a hysteresis of 1 cm. Statistical testing was performed using 2-way ANOVA.

Results

The data were divided into dynamic and static factors. Dynamic factors show movement or weight shifts, while static factors reflect information about a surface support and posture.

Dynamic factors (Table 1) gave three statistically significant results. Quadriplegics showed more lateral movement while paraplegics showed more zero-crossings on the Jay cushion than on the other surfaces. The arm force variation was largest with paraplegics and least with quadriplegic subjects.

Static factors (Table 2) showed more variation both between cushion types and handicap types. Quadriplegics gave the least variation between cushion types, while paraplegics show the most variation. The ROHO cushion generally showed both greater average normal and anterior center of force. Between handicaps, normal forces were proportionally higher with both quadriplegic and paraplegic subjects than with able-bodied subjects.

Discussion

Some of the differences between cushion types can be attributed to properties of the cushions themselves, rather than from any behavioral differences. Normal force is highest with the ROHO cushion since it offers the most thigh support, which transfers weight normally carried by the footrests to the seating surface. Thigh support is also apparent from the forward weight shift seen with the ROHO. The hard surface, giving the least support thigh support, showed both less average normal force and a more rearward center of force. There is also a tendency for greater seating shear with softer, less stable ROHO cushions than that of the firmer Jay cushion. This could be attributed to a desire of the subjects to feel stable, since the shear-deformed cushion would then have less movement.

The average force applied to the armrests was approximately 8% to 9% of the total body weight for the able bodied and paraplegics and approximately 5% for the quadriplegics. Since the combined weight of the hand and arm is 10% body weight (5), a significant reduction in seating force could be obtained by using the armrests. Quadriplegics, in general, have little or no arm extension and shoulder depressor function and therefore have less ability to lateral shift and lean on their arms.

The floating effect of the ROHO also would decrease the change in recorded position that occurs when a person attempts to shift his or her weight. Because of the softness in the lateral direction the user tends to slide to the center with a sideways lean. With the Jay cushion there were more frequent and large amplitude lateral movements of the center of mass. This should result in the temporary reduction of the pressure under one or other of the ischial tuberosities which may not occur as much with the ROHO.

The conclusions of the study are that the ROHO cushion tended to carry a larger average forward shear force and a more anterior position of the center of mass. With the Jay cushion, there were more frequent large shifts of weight and therefore possibly more short decreases in the pressure under the ischial tuberosities. The armrests tend to support 5% to 9% of the body weight. This suggests patients with ulcer problems should use armrests on their wheelchairs.

Table 1. Avg. Values of Dynamic Factors

		force nor. sd %	force shear sd (kg)	lateral pos. sd (cm)	A-P pos. sd (cm)	zero-cross	arm force (%body wt) sd
able body	ROHO	2.9	0.85	0.42	1.15	13.3	9.5
	Jay	2.4	1.88	0.78	0.47	19.0	8.9
	hard	3.2	1.38	0.76	1.15	18.8	9.8
quad	ROHO	3.1	0.76	0.34	0.27	11.3	7.7
	Jay	3.7	1.13	0.49	0.40	18.0	7.5
para	ROHO	4.7	1.06	0.42	0.42	16.8	11.2
	Jay	4.7	0.88	0.65	0.78	31.3	10.6

Table 2. Avg. Values of Static Factors

		force nor. (Kg)	force shear	A-P pos. (cm)	arm force (%body wt)
able	ROHO	69.3%	6.7	-1.7	7.5%
	Jay	66.1%	5.4	-2.7	8.3%
	hard	61.5%	4.8	-4.3	8.5%
quad	ROHO	77.6%	7.2	-2.3	5.2%
	Jay	74.2%	5.4	-4.0	5.7%
para	ROHO	76.4%	7.7	-3.6	9.9%
	Jay	73.4%	5.8	-5.2	8.2%

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IMPLEMENTING MAGNETIC RESONANCE IMAGING FOR THE QUANTIFICATION OF LOAD-BEARING BUTTOCKS TISSUES

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Introduction

Magnetic Resonance Imaging is a useful non-invasive technique used to investigate the various tissues of the body. It provides much better contrast between the soft tissues than other imaging methods. MRI is most commonly used in the *qualitative* evaluation of diseases and injuries within the body.

In the present study, a *quantitative* approach was taken to obtain direct physical measurements on living subjects. Without the luxury of an imager, these measurements could be obtained only by using cadavers, and even then, their tissue properties differ greatly from those of live subjects. The overall purpose of this investigation is to better understand exactly what changes occur between unloaded and loaded tissues that are highly vulnerable to necrosis initiated by prolonged tissue compression.

Methods

A Siemens Magnetom 1.0 Tesla whole-body MRI imager was used to acquire serial images of the lower pelvic area in the necessary supine position. Approximately 13 images (3mm slice thickness spaced 5mm apart) were acquired of each of the three loaded conditions imposed on the pelvic area of a normal subject of age 24. These imposed conditions were: 1) the freehanging buttocks (control), 2) the buttocks compressed under body weight only, and 3) the buttocks compressed under 9.15 Kg. placed upon the illiac crest. In conditions 2 and 3, the buttocks rested on a contoured cushion that was custom fit in order to distribute the loading force more evenly.

T_1, T_2, and Proton Density-weighted images were acquired at the very same slice position. Each type of image, which emphasizes different tissue components, was used in a different area of the investigation. Standard echo times (TE) and relaxation times (TR) were used. The images were transferred by tape in float format to a Masscomp image processing system. All images were rescaled from 12 bits/pixel to 8 bits/pixel for data analysis.

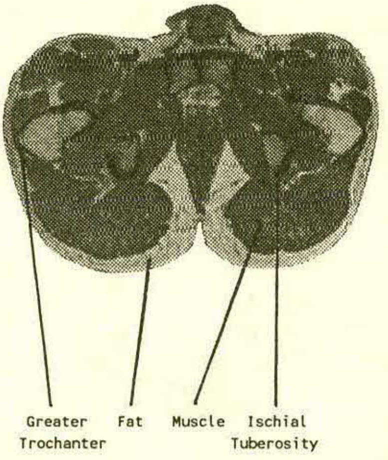
To calculate the muscle and fat volumes in each condition, the regions of interest in the image were extracted by outlining them carefully using a mouse. The T_1 images alone were adequate for this procedure. One program, ROI, set all pixels within the outlined region to one gray level, while another program calculated the area using the known image resolution. Volumes were then approximated by linearly integrating a series of cross sections of the buttocks over a 10cm span. This was done for both muscle and fat for each of the three loading conditions over the identical 10cm region.

Also in this investigation, 3-D wireframe structures of the fat and muscle of the buttocks were constructed for all three conditions. These wireframe structures were made by outlining the regions of interest in an image using a mouse. Along the outlines, there are points with known coordinates, and inter-slice connections are then made between points.

Finally, image processing and pattern recognition methods were used to detect subtle changes between uncompressed and compressed tissues. The muscles that lie between the ischial tuberosity and the seat surface are of primary importance, and subimages of this region were extracted from each image. The K-means clustering algorithm was simultaneously implemented on T_1, T_2, and Proton Density images of one slice of each condition. The algorithm essentially reduces the variability of the pixel gray levels of an image into only a few gray levels. It therefore can detect patterns in an image undetectable by the human eye. The pattern changes between the three loading conditions were then quantified.

Results

Shown below is one of a series of cross-sectional images of the lower pelvic area (unloaded condition). All calculations and reconstructions were performed using images like this one.



The results of the volume measurements are shown below:

	Muscle (cm^3) Volume	Fat (cm^3) Volume
Unloaded	1526.8	932.8
Bodyweight	1449.3	854.7
Bodywt + 9Kg.	1348.5	799.6

Percent Difference From Unloaded Condition

	Muscle	Fat
Bodyweight	5.1 %	8.9 %
Bodywt + 9Kg.	11.7 %	14.7 %

Discussion

In our preliminary investigations of the load-bearing tissues of the buttocks, the use of Magnetic Resonance Imaging for geometric quantification has shown to be highly feasible.
Accurate measurements can be made directly from the cross sectional images. Accurate calculation of cross sectional area, which is ordinarily an extremely difficult task, is a very simple summation of pixels with this technique.

3-D wireframe structures, which serve both as visual aids and as the framework for structural analysis methods such as the finite element method, are constructed with relative ease. Their construction through the use of MRI may be the best means of attaining accurate models of those buttocks tissues most susceptable to pressure sores.

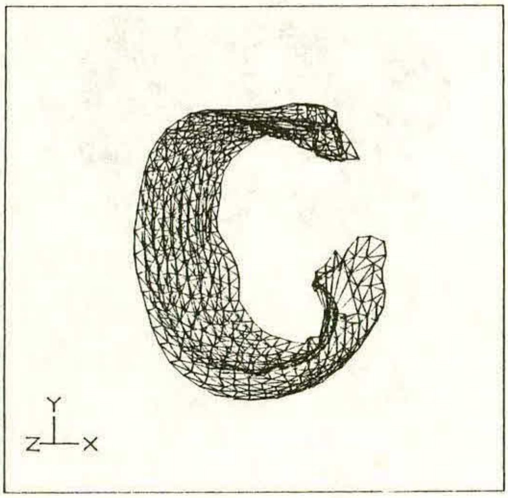


Figure 2. 3-D wireframe structure of fat layer of left side of unloaded buttocks.

For geometrical calculations and 3-D reconstructions, T_1-weighted images alone were demonstrated to be adequate. Any more than one image type would have deemed superfluous information, with more time and memory space lost.

However, in research that involves employing pattern recognition methods on MRI images, all three of the image types, i.e. T_1, T_2, and Proton Density, provide vital information. Therefore, it is recommended to operate upon all three image types simultaneously for the best classification of pixel intensities. This procedure is referred to as *multispectral* pattern recognition. The preliminary results of our investigation of this type produced inconclusive results, and is being pursued further. The quality of the acquired images is of paramount importance to the remainder of the process. It has not been determined whether MRI images have the necessary resolution and intensity uniformity in order to quantify significant changes in the composition of compressed muscle via pattern recognition methods.

A different method that uses relaxation times of the MRI images as an indication of the muscle composition has been reported recently [1]. Relaxation time refers to the amount of time elapsed when the individual protons of the matter being imaged flip from the down to the up alignment with the oscillating magnetic field [2]. Measurement of this relaxation time reflects the condition of the tissues at the molecular level. This method will be included within our investigation in the near future.

The mass of information collected from these investigations will serve both in the understanding of the actual necrotic process of pressure sores and will help provide manufacturers of hospital beds and seating systems with information needed to better prevent the necrosis.

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Seating Simulation as an Aid to Assessment

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Abstract

Special seating, mobility and communication systems have developed a great deal over the past decade. Many different approaches are available for the delivery of these systems, and the difficulty of making appropriate decisions has increased proportionately. The simulation of the position of a disabled person enables the prescriber and user or carer to make informed decisions based on quantitative information and is becoming more important in the process of prescription as the number technologies involved in rehabilitation increase. This paper describes a device which enables the simulation of position(s) with a wide variety of user sizes and types of equipment.

Introduction

As is well known, the optimum positioning of disabled people can be critical in the rehabilitation process. There are many variables to be considered to ensure the correct prescription and delivery of devices to achieve this optimum.

Heinrich[1], Hobson[2], Bardsley[3], Silverman[4], ourselves (as will be described) and others have routinely used some means of positioning disabled individuals as part of the assessment and prescription process.

The purpose of the Seating Simulator is to enable Seating Service Departments to quickly position and support disabled individuals, of a wide variety of sizes and orthopaedic deformities, in a manner which will allow confident and cost effective prescription of definitive seating systems and associated mobility and communication system.

Philosopy

The design allows adjustments to be made and for the individual to be moved in space without them being removed from the device.

The Simulator has flat surfaces which adjust to support seat, back, and arms at the appropriate angles. Head or neck support is also provided, along with individual foot and arm position markers. These flat surfaces are designed so that different types of support surfaces can be mounted on them to simulate modular, foam and plywood, bead and other seating systems.

By supporting an individual on these surfaces and adjusting them for the optimum position the device "simulates" the system to be prescribed. Once the prescribing team are content with the position they have achieved they are then able to take measurements from the simulator and thus determine precisely what is required for their client.

Description

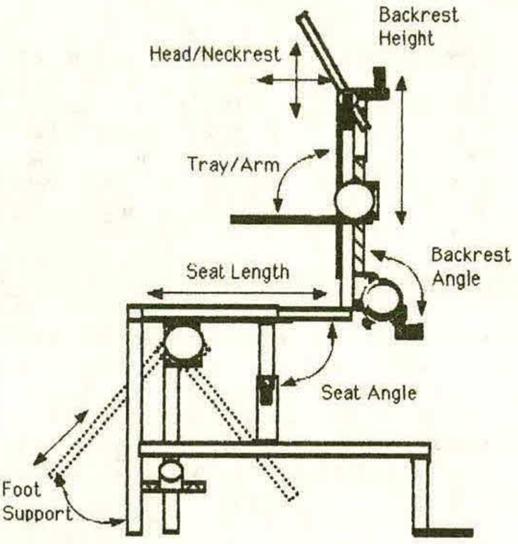
The frame is constructed in stainless steel with aluminium panels and uses well proven components to reduce costs and provide a robust construction and long life. The Simulator has the following features:
-adjustable to support children-large adults in a variety of positions, (56-220lbs & 52-78" ht., 25-100kg & 130-200cm ht.).
-able to accomodate a wide range of deformities from mild to severe.
-adjustments to the position of the person can be made without removing them from the Simulator.
-provide a base for different seating systems such as Bead, Matrix and various Modular Systems (eg Otto Bock), as well as an adjustable base for casting techniques (using vacuum consolidation).
-transportable in a small car (folded size of 20"Wx30"Lx30"H, wt.50lbs).

Clinical Experience

200 assessments have been carried out over an 18 month period and the Seating Simulator is now in routine use. Typically it is used with the vacuum consolidation technique using Expanded Polystyrene Beads in two Platilon Bags, one for the seat and one for the back, and a carefully controlled vacuum source to control and provide the contouring necessary for support. Otto bock headrests are used to provide head support. It has also proved of use in the fitting of Adult Bead Seating Systems and is used routinely for this purpose.

The extreme of the range of individuals positioned using the standard adjustments on the simulator is from: 3'9" (115cm) height, 42lb (19kg) normal male, to; 6"2" (188cm) height and 280lb (120kg) normal male.

Fig.1SeatingSimulator Showing AdjustmenAvailable



- Head/neckrest support can describe a 180° arc, length of radius arm for this arc can be chosen with continuous adjustment along chosen length (eg10"); continuous adjustment from midline L & R 0-6"; angular adjustment L & R ± 60°; up & down ±45°; further fore-rearward adjustment 0-4"

- Seat Angle +8° -20°
- Backrest Angle (rel. to vert. with horiz. seat) forwards 65° to 180° recline.
- Tray/arm Angle (rel. to vert. back)- individually adj L & R, 0° to 170°.
- Legrest Angle (rel. to vert. with horiz. seat)- individually adj. L & R, rear 55° to 48° forwards
- Footrest Angle (rel. to vert. legrest) individually adj. L & R, 0°-360°
- Seat Length nominal 13"-19"
- Backrest ht. nominal 18"-22"
- Armrest ht. low 6"-12" (backrest in low posn.) individually adj. L & R.
- Armrest ht. high 10"-16" (backrest in high pos) individually adj. L & R.
- Armrest width - individually adj. nominal 18.5" to 23"
- Legrest length nominal (horz. seat to footrest) 6"-19.5" - individually adj. L & R.

NOTE: The term "nominal is used where the length may be varied by the addition of packing pieces, etc..
Weight approx 23kg.
For convenience a pair of wheels are built in so that the Simulator acts as its own "trolley".
For transportation the 2 main components can be separated & weigh 9 and 11kgs each.
Seat tested horz to 20°recline and back tested vert. to 65° recline, 120kg normal male. Suggest 100kg limit.
NOTE: These measurements are approximate to ± 0.5", 2° & ± 2kg.

Conclusions

1. Assessment devices of this type, associated with comprehensive clinical evaluation techniques, have proved of great value over time in the cost effective provision of appropriate seating systems and should be incorporated into departments which offer Special Seating Services.

2. Routinely it is being found that the "appropriate" position for our clients cannot be achieved with standard wheelchair bases, and for the UK a small wheeled base is being developed which will enable the severely disabled to be positioned.

3. It is common to find that more than one fixed position is desirable; ie, a reclined position for resting and an upright position for functional activities.

4. There is an educational benefit in being able to quickly and easily demonstrate different postures and their effects on function and comfort, when teaching seating principles.

Ackowledgements

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Coordination of Rising from a Chair in Young and Elderly Women

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Abstract

Falls during daily living tasks are a serious problem in the elderly. Musculoskeletal factors such as muscle strength contribute to risk for falling in the elderly, but it is not known how these factors affect movement coordination and postural instability. To understand how musculoskeletal factors affect coordination and balance during a task that is associated with high fall risk, we investigated rising from a chair in young and elderly women. Kinematic and kinetic data were collected and analyzed for normal and fast movements. Results showed that coordination was similar in young and elderly women, and that differences between the groups were due to differences in movement speed. Loss of balance during rising from a chair may be related to the inability to generate sufficient muscle torques to control the body mass.

Introduction

Falls are a serious problem in the elderly. Although many factors contribute to falls, musculoskeletal factors have been associated with falls in both community-living and residential-care populations (1-4). In particular, decreased muscle strength with aging has been identified as one of the risk factors for falling (3,4). It is not known, however, how changes in muscle strength that occur with aging affect coordination and balance during movement. For example, difficulty in rising from a chair is associated with risk for falling (2), yet the musculoskeletal factors that contribute to instability during that task are not well-understood. The purpose of this study was to quantify the affect of musculoskeletal factors on coordination of rising from a chair in young and elderly individuals, and to identify the differences in coordination that may contribute to risk for falling in the elderly.

Methods

Subjects in this study were healthy, active, and community-living women that were either young (24 $\pm$ 2 yrs; n=6) or elderly (71 $\pm$ 6 yrs; n=17). Subjects were asked to rise from a standard height chair at both "normal" speed and "as fast as possible", without using their arms for assistance. Retroreflective markers were placed over the fifth metatarsal, lateral malleolus, lateral epicondyle, greater trochanter, and acromion process to demarcate foot, shank, thigh, and trunk segments. Ground reaction forces were detected using a force plate under the subjects' feet. Video data were collected (60 Hz) and digitized using the Motion Analysis system. Subsequently, motion data was digitally filtered with a low-pass cutoff of 6 Hz, and differentiated to obtain velocities and accelerations. Joint torques were calculated using a Newtonian formulation of the equations of motion and mass parameters estimated from regression equations (5).

Results

Mean movement time was greater for elderly than for young subjects in both normal (1.61 $\pm$ 0.19 s vs. 1.52 $\pm$ 0.21 s) and fast trials (1.20 $\pm$ 0.06 s vs. 0.97 $\pm$ 0.16 s). When young and elderly subjects that moved at the same normal speed were compared, however, the young subjects were able to move faster in the fast trials than were the elderly subjects (36 $\pm$ 2 % vs. 24 $\pm$ 11 %).

Joint trajectories were similar for both groups. First the hip flexed, and then the knee and hip extended together as chair contact was lost (Fig. 1). Hip and knee joint torque patterns were also similar for all subjects across speeds. Peak hip torque was similar at both speeds for all subjects (normal 78 $\pm$ 17 Nm; fast 74 $\pm$ 17 Nm), but knee torque tended to increase with speed (normal 80 $\pm$ 26 Nm; fast 92 $\pm$ 19 Nm). The pattern of ankle torque varied among subjects. Subjects with slower movement times tended to generate dorsiflexion torques just after chair contact was lost, whereas subjects with faster speeds tended to generate plantarflexion torques.

The change in linear momentum of the body center of mass with change in movement speed was similar for elderly and young subjects. As movement time decreased, the magnitude of the vertical momentum (normal 32 $\pm$ 5 $kg \cdot m \cdot s^{-1}$; fast 44 $\pm$ 7 $kg \cdot m \cdot s^{-1}$) increased substantially, while the horizontal momentum remained the same (normal 28 $\pm$ 6 $kg \cdot m \cdot s^{-1}$; fast 30 $\pm$ 8 $kg \cdot m \cdot s^{-1}$).

The pattern of the vertical ground reaction force changed with movement speed. In the fast trials, the body center of mass was accelerated downward at the end of the movement, primarily through forward angular acceleration of the trunk, resulting in a pronounced minimum in the vertical ground reaction force (see arrows in Fig. 1).

Discussion

Results showed that young and elderly women moved similarly during rising from a chair. Linear momentum of the body center of mass changed with movement speed for both young and elderly subjects, as others have reported for young subjects (6). We believe that differences in coordination between elderly and young subjects are explained by differences in movement speed, rather than by fundamental differences in the ability of these elderly women to coordinate the motor task.

We found that large joint torques were needed to control the momentum of the body center of mass, not only at the initiation of the movement, but also at the end. Loss of balance during rising from a chair may be related to the inability to generate sufficient muscle torque to control the body mass. In frail elderly subjects, muscle strength may present a serious limitation to safe performance of the task.

Acknowledgements

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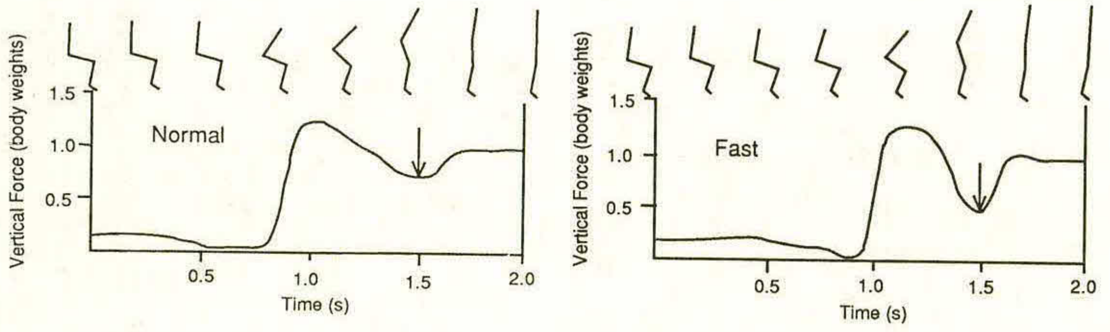

Vertical ground reaction force during rising from a chair in an elderly woman. Vertical force is normalized by body weight. Stick figures show body positions. Force during a normal speed movement is shown at left, and during a fast speed movement at right.

POSTURAL SWAY: BEYOND ASSESSMENT TREATING SWAY WITH FEEDBACK

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INTRODUCTION

Postural sway and stance asymmetry have been identified as characteristics of neurological insults which significantly impact the ability of the patient to stand independently and ambulate. Because of this, numerous efforts have been made to evaluate and quantify changes is postural stability.[2,3,6] Evaluation of postural sway alone does not improve patient function. To produce changes in functional skills, therapists must be able to produce changes in the characteristics that they are evaluating. Some means of treating stance asymmetry and postural sway must be developed.

One component of the changes in stance and postural stability appears to be alterations in sensory feedback of body position.[4,5,8,9,10] This sensory component of the postural stability may be treated through immediate feedback of the patient's position in space.

METHODS

Postural sway may be monitored either through directly measuring movement in space or can be monitored indirectly through foot-ground pressure sensing. If the therapist wishes to present feedback of stance asymmetry, the foot-ground pressure technique provides the most direct means of monitoring. Numerous stance systems have been developed for assessment research, and for this research, the forceplate developed jointly by Anson, Prouty, and Schumway-Cook was utilized.

In providing feedback of stance, some form of immediate, intuitive display of postural sway and stance asymmetry is required. Earlier research has demonstrated that visual display of position information is more effective in controlling posture than either auditory or vibratory feedback.[1] Such feedback must track changes with minimal delay (less than .5 seconds), be easily understood, and be engaging in order to provide effective training. In order to be interpreted by individuals with perceptual deficits, the feedback must not contain distracting information.

The feedback chosen for this research was similar to that used in cuing head position in earlier research.[1] Feedback was provided by the video screen of an Apple II computer placed at the eye level of the patient. The screen displays a target area representing symmetrical stance and the range of normal sway. The display also includes a dynamic marker in the form of a "+" representing the center of pressure of the patient. This center of pressure is calculated as the difference between the right and left foot pressures for the X axis, and the difference between the heel and toe pressures for the Y axis. If the patient's stance is centered over his/her feet and stable, this "+" is centered in the target area. If more than half of the patient's weight is over the left foot, the marker is shifted to the left in proportion to the asymmetry. As the patients sway over their bases of support, the marker moves freely about the screen to display the movement. The "+" marker position is updated from 20 to 60 times per second, depending on the training mode being used. No other information is provided on the video screen during testing phase.

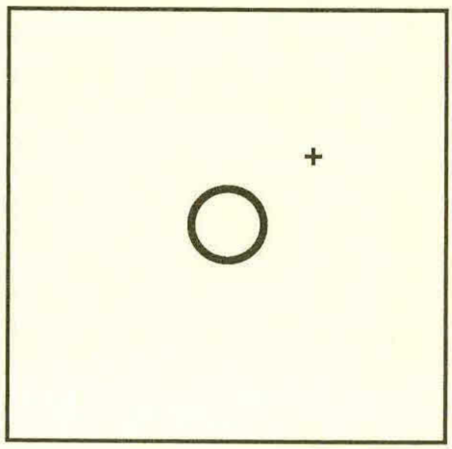

Figure 1

In early testing, it was discovered that, while the feedback was immediately understood by patients, and very engaging, many individuals with hemiplegia were unable to achieve centered stance in early stages of training. The relatively small target area produced frustration and encouraged the patients to assume bizarre stances in their efforts to reach the target area. To reduce this frustration, the feedback was altered to compute the patient's center of stance from a pretest session, and expand the target area towards the patient's functional center of pressure. (See Fig. 2) This technique reduces frustration by provided the patient with a higher success rate, while automatically scaling the target zone as the patient improves.

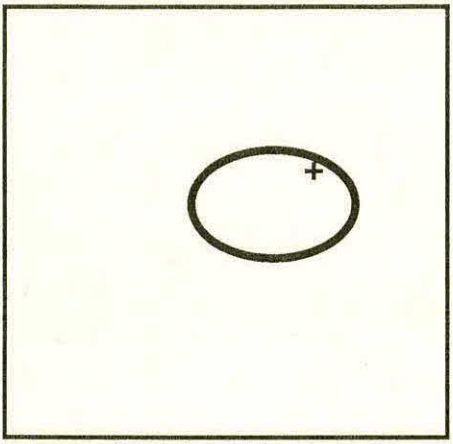

FIGURE 2

RESULTS

As reported elsewhere[7], this type of feedback of postural sway and stance asymmetry was effective in reducing stance asymmetry in hemiplegic patients, with all experimental subjects showing decreased asymmetry of stance. For half of the experimental subjects, the decrease in asymmetry was accompanied by a decrease in postural sway. For the other half of the experimental subjects, the decrease in asymmetry was accompanied by an increase in postural sway. We hypothesized that this was due to increased loading of the leg with muscle weakness. By comparison, only 25% of the control subjects, who were receiving traditional clinical therapy, showed a decrease in stance asymmetry, and only 12.5% showed decreased postural sway.

CONCLUSIONS

The results of this research show that visual feedback of center of pressure can be effective in improving the stance and sway characteristics of individuals with neurological injuries. The factors which seem vital in providing effective feedback are: immediate updating of the position information, providing clear feedback with a minimum of distracting stimuli, and providing the feedback in a way that captures and holds the attention of the patient. The system described was updated 20 to 60 times per second, was immediately understood by all subjects, and caught and maintained their interest during treatment.

ACKNOWLEDGMENTS

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INSTITUTIONALIZED ELDERLY WHEELCHAIR SEAT COMFORT INTERIM REPORT

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INTRODUCTION

In August 1989 we began a one year investigation of wheelchair seat comfort for elderly nursing home residents. The study has been designed to relate subjective reports of discomfort to a more objective parameters such as sitting pressure, body type, etc. This paper outlines the study design and assesses its effectiveness based on our experience through the data collection phase of the project.

BACKGROUND

An increasing number of elderly live in nursing homes, 35 percent of whom use either a standard folding wheelchair or a geriatric wheelchair. A high incidence of wheelchair seating needs, including a priority need for increased seat comfort, result from a combination of disabling conditions and functional limitations which presently used wheelchairs fail to accommodate. As of 1983 there were 1.3 million or 5 percent of the U.S. elderly living in nursing homes (1).

Wheelchair seating problems experienced by the elderly include difficulty in chair propulsion, unsafe transfers to and from the chair, postural instability, pressure sores, and discomfort. Bardsley (2) in a survey of seating needs of the 200,000 people in Dundee, Scotland found that 80% of those with problems were elderly and that 56% of the institutionalized elderly experienced seating problems. Epstein (3), in a needs assessment study conducted at a 536 bed nursing home in the New York metropolitan area, found that 26% of the residents had propulsion, transfer, and postural stability problems aggravated by wheelchairs which were too big. In a 1987 study of 200 randomly selected residents from six Memphis area nursing homes we found that discomfort and impaired mobility were most frequently reported in response to specific questions and most often cited as the worst thing about the wheelchair.

Many of the reported problems stem from the use of inadequate wheelchairs which in turn results from a combination of factors including a lack of awareness that problems exist and a very limited body of knowledge providing direction regarding appropriate wheelchair prescription. The goal of our present study is to contribute to this body of knowledge a better understanding of the often mentioned problem of seat discomfort.

STUDY DESIGN

Subject selection
A representative sample (50 subjects) of the 1100 Memphis nursing home wheelchair users was selected from four nursing homes. To qualify as test subjects the residents had to be at least 65 years of age, use a standard wheelchair for at least four hours a day, have at least partially intact sensation over their buttocks and thighs, and be able to reliably rate their seat comfort.

Data Collection
For each subject we recorded diagnosis, mental status, brief personality profile, functional abilities, body dimensions, sitting posture, and wheelchair and cushion specifications and dimensions.

Subject seat comfort was rated using a 5 point comfort scale which ranged from "very comfortable" to "very uncomfortable". Ratings were made on the subject's present wheelchair seat which often included overlying materials such as folded sheets or cushions. The subjects were asked to rate how their seats felt "right now" and, using a separate scale, if their seat was ever uncomfortable. Other questions included rating their seat as too hard/correct/too soft, cold/ correct/hot, and too high/correct/too low.

Sitting pressure was recorded for each subject using the Oxford Pressure Monitor Mark II (OPM) (Talley Medical LTD, Hertfordshire, England). Six 3"x4" sensors were taped together and sandwiched between urethane film. Each sensor consisted of a 3x4 matrix of 3/4" diameter air cells. This resulted in a sensor area large enough to establish the peak pressures for most subjects without the inconvenience of repositioning the transducer. Sitting pressure was measured three times. The resident stood up (assisted) between measurements. Peak sitting pressure was also measured using the Talley/ Scimedics hand held pressure evaluator.

Data Analysis (Planned)
The association between perceived comfort and peak pressure will be assessed using analysis of variance (ANOVA) in a series of planned comparisons.

In addition to sitting pressure we will investigate the relationship of other factors to seat discomfort. Subjects' cushions will be categorized as to construction, thickness, and surface material. The association between perceived comfort and cushion type will be investigated using a Chi Square analysis. The association between cushion type and peak pressure will be examined using a one way ANOVA. Also considered will be body type, number of years of wheelchair use and sitting posture.

DISCUSSION

Because the data analysis has yet to be done, we cannot comment on the success of the overall study. However, the study tasks which have been completed, the subject selection and data collection, have gone smoothly.

The initial challenge of finding nursing home elderly capable of reliably making comfort judgements proved to be much easier than anticipated. Nursing home staff were accurate in identifying cognitively capable residents. Approximately 75% of those suggested by the staff were qualified for the study. The cooperation of the residents also made our job easier. Most agreed to participate without knowledge that they were entitled to a $15.00 post study payment. Only four refused to participate in all or part of the study.

Subjects seemed to have little problem using the discrete five point comfort scale to rate their seat comfort. This was in marked contrast to a previous trial with 10 similar subjects in which we used a continuous seven point scale. We failed however in controlling the amount of time the residents sat in their chair before their comfort rating. Although we regret that this has introduced an unwanted variable which has been better controlled in studies with younger able bodied populations, we feel that more stringent control would have exceeded the patience of nursing home staff and residents. Fortunately, preliminary analysis suggests that sitting duration was a randomly distributed variable and had no significant effect on the comfort ratings.

As anticipated, measuring sitting pressure was the most time consuming (45 min average) and most difficult part of the data collection process. A few residents were eliminated from consideration due to the stress of multiple transfers required by the pressure measurement protocol. In order to minimize discomfort we eliminated the Talley/Scimedics measurements for several residents.

Given the limitations of pressure transducer technology in general, however, we had a relatively easy time. After pre-study problems with sensor quality, the OPM worked flawlessly. The OPM's averaging mode which scanned each air cell every four seconds and continually averaged the results reduced error due to subject movement. The multi-sensor transducer eliminated the need to reposition the transducer for all but six subjects.

CONCLUSIONS

Experience to date suggests that the study design has been generally effective in investigating institutionalized elderly seat comfort. Success in subject selection and the willingness of subject and caregiver participation exceeded our expectations. Data collection was occasionally compromised due to the limitations of the study population.

ACKNOWLEDGEMENT

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The Effect of Age on Spontaneous Gross Positional Turning During Recumbency and its Relevance to Pressure Sore Prevention

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ABSTRACT

A fundamental parameter in the causation of pressure sores is the length of time that pressure is exerted on any tissue site. This suggests that vulnerability to pressure sore development is a function of any single period of inactivity. In a study of 72 healthy volunteers of both sexes within the age range 21 to 92 years, we discovered a significant correlation ($R = 0.961$) between age group and the maximum time between spontaneous gross positional turns during recumbency. No correlation was found between the mean turning interval (frequency of turns) and age.

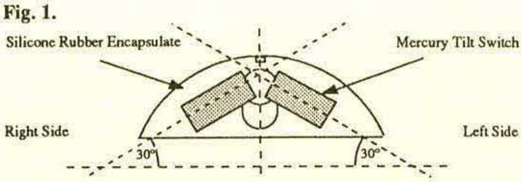
INTRODUCTION

It is the pressure-time threshold that is of fundamental importance in the causation of pressure sores. There is no precise data from human studies but a critical pressure-time relationship has been accumulated from actual patient experience (4). Studies carried out (1) using pO_2 as an indicator have shown that thresholds for anoxia varies between individuals and may depend on their health. With reference to the history of in-hospital pressure sore management, small axial turns or lateral shifts are found to be ineffective in pressure sore prevention. Empirically two-hourly turns have been found to be effective for preventing pressure sores in most patients. We therefore postulated that the maximum time spent in a single recumbency position for each subject would be more indicative of their tolerance to tissue loading than the frequency of turns used in other studies of this nature (3).

EQUIPMENT

The measuring apparatus in this study comprised a transducer that measured tilt angles of greater than 30° to the horizontal (see Fig. 1.) and a silent event-driven digital data storage device. The transducer allowed the identification of five gross recumbency positions, namely; Prone, Supine, Right Side, Left Side and Semi-recumbent. On completion of the study the data was transferred to a microcomputer for analysis.

Fig. 1.



Multiple tilt transducer showing three mercury tilt switches mounted at 30° to the horizontal, two switches are mounted in the X-Y plane, the third lies in the Z plane.

MATERIALS & METHOD

The studies were carried out over three consecutive nights within each volunteer's home, thus minimising the effect of the surroundings on the subject's sleeping habits. A questionnaire, completed upon rising, was used to establish each volunteer's sleeping regime, noting any subjective abnormal occurances and assessing subjectively their quality of sleep during the study period. A minimum of six hours recumbency was required for the information to be included in the final data analysis.

RESULTS

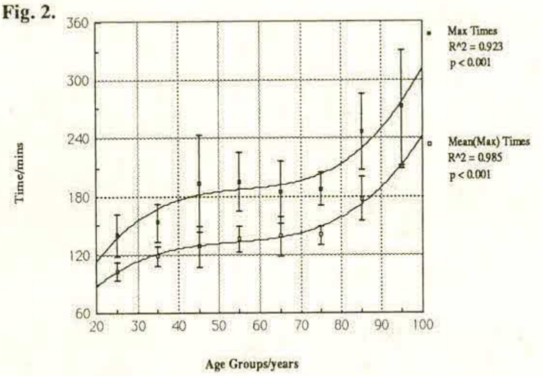
The equipment used for this study provided highly reproducible results. Gross positions assumed for less than 1 minute were disregarded as these were considered insufficient periods for tissue recovery (2).

Three parameters were identified as being of most value in characterising gross turning episodes in relation to pressure sore prevention:-

1. The mean time between gross positional turns (the inverse of the mean turning frequency).
2. The maximum time spent in any recumbency position throughout the study period (3 nights).
3. The average maximum time between gross turns (the individual maximum for each night study averaged over the three nights).

Before correlating the sleep data with age, the results were analysed so as to assess whether the parameters of interest were influenced by the measuring apparatus. No significant difference could be found between nights with a one-way analysis-of-variance using either the mean turning interval or the average maximum turning interval. We were therefore able to incorporate all the data into the age versus turning interval analysis.

Fig. 2.



As can be seen from Fig. 2., when the data has been arranged into a series of age groups very high correlations exists between maximum turning interval and age (R = 0.961), and between mean maximum turning interval and age (R = 0.992), using a third order polynomial fit (if these parameters are plotted directly against age ie. a simple scatter diagram, though the correlation coefficients are much lower the p values calculated using the T distribution remain the same).

DISCUSSION

There are a number of fundamental questions that must be answered regarding normal spontaneous turning and its importance in the prevention of pressure sores.

If, as is generally assumed, pressure sore formation depends on pressure-time thresholds, then a critical parameter must be the maximum turning interval rather than the frequency of turns. No correlation was found between the mean turning interval (frequency of turns) and age. The increase in maximum turning interval with age in the healthy volunteers in this study (eg. 140 minutes in the 20 to 30 years age group as opposed to 270 minutes in the 90 to 100 years age group) may help to explain why pressure sores are more prevalent in the elderly. However, despite the fact that the elderly patients in this study exceeded the accepted two-hourly turning period used in the prevention of pressure sores, none of the volunteers developed a sore. The fact that pressure sores develop in the elderly may be due to additional factors such as diminished sensation and a poor systemic status which allow critical thresholds for pressure tolerance to be exceeded, these factors further reducing spontaneous movements and tissue tolerance levels.

In conclusion, from our results we can state that there exists a relationship between movement patterns during recumbency and age but the case that *'spontaneous turning is a natural preventative response to pressure sore development,'* is still not proven. Further work will now be directed at using this baseline information in comparative studies with in-patients prone to pressure sore development, and establishing the causality behind the age-movement relationship.

ACKNOWLEDGMENTS

We would like to thank "Action Research for the Crippled Child" without whose financial support this work would not have been possible.

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A Software Tool for Manipulating Objects in Space

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ABSTRACT

A human beingdeals with objects in a far more abstract manner than a robot. When we wish to manipulate an object, our primary concern is to identify the object, usually visually. Our concern is for size, shape, color and type. When we reach for and manipulate an object, we are hardly conscious of dealing with the specific location of the object. A robot, on the other hand, needs the specific location of the object, and a way to approach it. The type and characteristics of the objects are of little concern. When a person deals with a robot, a gap exists between the "human approach" and "robotics approach." In order for robots and human beings to interact effectively, a tool is needed to bridge this gap. This paper describes a library written in the C programming language which fills this need.

OBJECTS IN SOFTWARE

The basic task of this library is to store and maintain information relevant to physical objects in a data structure. The library allows us describe objects in a manner natural to us while providing the coordinates needed by the robot. Each object in the data structure contains the followingfields:

1) a name
2) a list of characteristics
3) a set of coordinates
4) an approach vector
5) a list of objects to which it is bound
6) a path

The purpose of each of the fields will be explained below.

REFERENCING OBJECTS

Each object is described by a *name* and a set of *characteristics*. When any operation is to be performed on an object, we retrieve information about the object from the data structure by providing the name of the object, and enough of its characteristics to uniquely identify it. For example, an object could have the name "ball" and the characteristic "blue". If it were the only object with the name ball in that data structure, then simply providing "ball" would be sufficient. However, if there was a second "ball" with the characteristic "red", "blue ball" would be needed to retrieve information concerning the ball that was blue. Ambiguous descriptions (i.e. the description describes more than one object) produce an error condition[1].

COORDINATES OF OBJECTS

Information about an object may include a set of coordinates. These coordinates describe the position and orientation of the object in space. In order to retrieve an object with the robot using the library:

1) use the objects library to find an object in a data structure by giving its name and some unique set of characteristics.
2) get the set of coordinates from the object.
3) tell the robot to go to this set of coordinates and grasp the object.
4) relocate the object.
5) read the position of the robot and use it to update the recorded set of coordinates of the object.

The library is independent of the way one wishes to represent spatial coordinates, since different representation schemes are more appropriate for different robot architectures. The coordinate data structure is provided by a separate module which can be replaced by an experienced programmer.

APPROACHING OBJECTS

The user will often wish to approach a physical object from a specific direction. This approach information is stored as a vector. The coordinates of an object include both position and orientation. This information completely defines where the gripper of the robot should be in order to pick up the object. The approach vector is a combination of the direction specified by the orientation coordinates, and a magnitude stored in the object data structure. This vector, together with the position of the objects in space, defines a new point in space from which the robotic manipulator can safely approach the object.

BINDING OBJECTS TO OBJECTS

Objects in space can be *bound* by any number of forces: gravity, velcro, magnetism, etc. When one of two *bound* objects is moved, the other moves also. The library supports these relationships logically by providing a means to logically bind objects together and later unbind them. When the set of coordinates of a given object is updated, the set of coordinates of any objects bound to it may be updated as well. The coordinates of the bound object will be modified such that the physical relation between them will be maintained. The operation of binding objects together is unidirectional (i.e. binding α to β does not mean β is bound to α)[2]. One object can be bound to many others.

For example, if there is a cup on a tray and the robot

1. The only exception to this is if the description describes one object exactly. For example, if there is a ball with characteristics "blue" and "big", and a second ball with the characteristic "blue", looking for "ball" would produce an error, because it describes both of the objects. Looking for "blue ball" however, would refer to the latter of the two objects since it is describes completely.

2. Bidirectional bindings can be achieved by simply binding α to β and β to α.

knows the coordinates of both the cup and the tray, and then moves the tray, we can see that the cup has moved with the tray; but we don't know the cup's coordinates in terms of something the robot can understand. If the cup is bound to the tray, however, when we update the coordinates of the tray we tell the library to also update the coordinates of the cup. The library will then calculate the new position of the cup. Note that moving the cup will not alter the position of the tray. Unidirectional bindings reflect this by allowing us to bind the cup to the tray, but not the tray to the cup.

OBJECTS IN PATHS

The library also supports information about paths. The major difference between *bindings* and *paths* is that each object may only be a member of one path but may be bound to many objects and have many objects bound to it. A path can be thought of as a series of objects bound together in a specific sequence. An entire path can be moved simply relocating a single member of the path.[1]

Paths have several uses. They can be used to define a path for the robot to follow. In this case the information stored in the data structure describes points in space rather than physical objects. This will allow us to define a set of points in the working space of the robot, and then later have the robot traverse this set of points. This is an easy way to define a simple task. For instance, if you had a number of jars each with something inside and you wanted to define a sequence of actions to unscrew the lid of the jar, set the lid of the jar on the data structure, remove the object inside the jar and set the object on the data structure, and then put the lid of the jar back on again. We can define the set of points the robot needs to traverse in a path. When we need to open a different jar we can just redefine the point for the lid and tell the library to move the rest of the path with it.

POSSIBLE USES

The library was initially designed to be used with a programming environment for rehabilitation robotics to build a robot independent platform for applications to be developed for rehabilitation robotics[1]. Examples of other applications include speech driven systems where the name and characteristic features of the data structure provide a natural interface to a language processing system. Simple English words can be parsed into a set of commands to look up information on a specified object, find its coordinates and then have the robot perform the necessary operation. The same basic strategy can also be used with either a menu or icon based system. The library could also be used as part of an interpreter such as Calvin[2] or Curl[3][2].

1. Objects bound to the other objects on the path are also updated. The update is done recursively.
2. This work was inspired by CURL [3]

PERFORMANCE

Benchmarks have been taken on the library to test its speed and capacity. The tests were run on a 20 MHtz Intel 386 based system running MS-DOS with 640K of RAM and a 64K cache. The average test case was taken to be objects with an average of 4 characteristics per object, being bound to 3 other objects with average length of the names and characteristic being 5 characters with each character string being used 4 times (they are each stored only once). We were able to get 2400 of these average object into the data structure before running out of memory. The time to completely create and install an object was relatively constant at 5 milliseconds until the machine ran out of far heap space. The time per object then increased to 1100 milliseconds until there was no memory left at all. Structure operations will be slowed when memory is exhausted

FUTURE WORK

Plans have been made to extend the library in three ways. Bindings will be allowed that are 6 dimensional. 6 dimensional bindings will treat each dimension independently. For example, an object could be bound in the z axis only, so that when the first object is moved, the second object will only move along the z axis.

Secondly, more complex approach vectors will be allowed. At the present, only approach vectors that are along the axis defined by the orientation coordinates of the object are allowed. In the future, the approach vector will be any arbitrary vector that ends at the defined coordinates.

Third, intersecting paths will be supported. Currently an object may be bound to many other objects but may only be a member of one path. This restriction will be lifted.

ACKNOWLEDGMENTS

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DEVELOPMENT OF A ROBOTIC VOCATIONAL WORKSTATION

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Abstract

The Robotic Vocational Workstation II (RVWII) is a second generation prototype voice-controlled robotic system that has been researched and developed using the Interactive Evaluation process, an iterative, stepwise refinement methodology. The Robotic Vocational Workstation II is targeted to individuals with little, if any, use of their upper limbs. Persons with these severe disabilities were previously considered unemployable. The goal has been to create a robotic system which will allow a person with upper limb physical disabilities to be gainfully employed full-time (eight hours). The process of integrating an intelligent human and a smart advanced technical device, such as a robot, requires careful consideration of factors from multidisciplinary perspectives. This paper will summarize the development of the RVWII from two of those perspectives: from the design of the system's environment and from the design of the system's software.

Methodology

The Interactive Evaluation process was conceived to facilitated the creation of systems incorporating recent advances in robotic technology and artificial intelligence, and to gather research information on human-machine integration[1]. An interactive approach is necessary to create relevant technological interventions. A process approach included:

a) identifying unmet or undermet needs
b) extrapolating these needs to other application domains and creating a matrix with needs on one axis and technical capability on the other
c) evaluating feasibility from technical and clinical (human) perspectives
d) assessing prioritized applications for their diffusion success potential

Background

Many attempts at stationary robotic assistants have been low-cost demonstration, proof-of-concept prototypes lacking reliability or robustness. This was often the result of size and cost constraints which necessitated the selection of "educational' manipulator technology lacking industrially rated components and robustness. These prototypes were usually oriented toward children and highly individualized redundant solutions. Other projects utilizing "high-end" technology also suffered from high manipulator costs, low manipulator payloads, insufficient attention to user ergonomics, and a lack of reliability due to their exploratory nature. Positively, many were concerned with pragmatism and economic issues, although these concerns were not translated into working systems. Overall, the potential for robotic assistants has been clearly established but the evaluation of their reliable use in actual user environments has not been adequately documented.

Results

The first generation of the system (RVWI) was tested at two rehabilitation centers and placed in an acute care facility. A volunteer with Muscular Dystrophy (previously unemployable) performed actual job tasks as a financial analyst. That system was used continually (8 hours/day, 4 days/week) for 7 months. However, problems with the robotic technology used in the RVWI made portions of the system inadequate for real-world tasks. It was these problems that prompted the development of the RVWII, which employs newer, more robust robotic and voice technologies. The research results are more completely described elsewhere[2].

The second generation RVWII has been field tested by 12 users with a spectrum of disabilities at 6 different sites. This research resulted in the identification of over 600 office related employment categories. Continued beta testing in a variety of work sites is underway.

System Environment Design Perspective

The design principles used in the creation of the RVWII system have been derived from classical human factors, product design and ergonomic guidelines. These have been integrated with health service information regarding persons with a wide range of disabilities. The concept of **accessibility** for the human, the robot, and the workpieces in the environment directed our design effort. This effort took the following issues into account:

- Human Factors
- Robot Factors
- Modularity/Transportability
- Adaptability/Adjustability
- Availability/Repairability of subcomponents
- Materials Costs
- Dimensional constraints

By combining these issues we created an aesthetically appealing office environment well suited not only for the disabled person and the robot, but also for a wide range of non-disabled users who might utilize the workstation during the hours the disabled person is not working.

Careful consideration was taken in the design of the individual workstation tables to account for adaptability to after-hour tasks. This modular design allows for greater flexibility and offers the capability of removing the robot portion of the system to do odious or mundane tasks in the remaining hours of the day. This system capability can be used to offset the initial cost of the system.

System Software Design Perspective
The RVWII software consists of a specially designed program that controls a robotic manipulator, a horizontal track, a customized voice recognition system, and a telephone management system. Through this program, a disabled user gains full control over all of the systems functions through voice control. The design of this software had to satisfy the following constraints:

- User friendly and user customizable
- Online help
- Small program size (occupying less computer memory) with maximum functionality
- Accessible from within other software packages

By following these constraints and gaining end-user input during the development process, we were able to create a powerful, flexible, voice controlled robotic system.

The RVWII is designed to operate under the MSDOS environment on any IBM PC XT or compatible. However, the design of the software makes it possible for the RVWII to operate on any IBM PC AT, 386 machine, or full compatible, to accommodate office environments with more sophisticated technology. The IBM PC line was initially chosen for its wide use in the business world. A new generation of RVW is being developed to take advantage of other computer technology, such as the Apple Macintosh system, thus expanding the number of existing offices with which the system is compatible.

Conclusion
Each year, thousands of dollars and many human hours are spent in the rehabilitation of individuals with disabilities such as quadriplegia due to spinal core injury, multiple sclerosis, muscular dystrophy, ALS, other degenerative neuromuscular diseases, cerebral palsy, and amputation. It is indeed frustration for cognitively intact individuals who primarily reside in wheelchairs and have limited upper limb capabilities to undergo the long process of rehabilitation only to find string barriers to employment. The ability to work is especially important in our society where one's identity is closely linked with worthwhile employment. The integration of robots and voice technology into workstations that are compatible with a wide range of environments and are capable of preforming useful tasks for humans is a significant milestone in realizing this objective.

Cost will clearly be a major consideration in the decision to employ disabled individuals with sophisticated robotic assistive devices. One criterion for justifying the relative cost advantage of the RVWII is economic payback. The cost of the RVWII, with a $50,000 target purchase price, will be paid back in decreased disability payments and increased wage tax payments in 5 years for workers earning $20,000/year, and 3 years for workers earning $35,000/year. Additional cost justification can be derived from the paybacks associated with putting the system to work beyond the 8 hours work day.

Cost can also be reduced if a general purpose system, rather than an 'individual specific' device, is created; economies of scale in manufacturing are more easily generated with more flexible products. One objective in creating a general purpose RVWII has been increasing the size of the potential market to include a wide spectrum of office workers with minimum to severe disabilities.

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PRELIMINARY EVALUATION OF A VOICE-CONTROLLED ROBOTIC WORKSTATION

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INTRODUCTION

Several different approaches have been taken in the application of robotics as an aid for the disabled [3]. We have focused our efforts on developing a voice-controlled, robotic workstation which is easily programmed by the technically non-trained user. A real time, menu driven control language has been developed to enable users to customize their own library of robot motions as their needs change. We employ a record-playback method for teaching the robot new tasks. Users guide the robot through the work space using voice commands and indicate points through which the robot should return when that motion is replayed. The control language also assists the user in the development of a structured vocabulary to access robot tasks [5].

There is little discussion in the literature on quantitative methods for the evaluation of robotic workstations. A similar lack of methodology existed in the area of augmentative communication before Goodenough-Trepagnier and Rosen presented their "CLT" analysis [4]. Their methodology is based on Fitts' investigation of motor control tasks. Fitts demonstrated that inter-target distance and target tolerance could be used as an index of task difficulty (ID) and that task time is a linear function of ID. In one of the few quantitative studies of user productivity when teaching a robot, Corker *et al* [1] used Fitts' ID as a standard for ranking tasks.

We report on initial tests performed to evaluate the ability of users to teach the robot using the voice-operated control language. A secondary objective of this study is to gain further insight into the applicability of Fitts' Law as a standard of task difficulty when using a voice-controlled robot to manipulate objects.

METHODS

Four subjects, one with Duchenne's muscular dystrophy, recorded voice samples of the vocabulary for the speech recognizer and were trained on the use of the robot.

Each subject was asked to teach the robot three pick and place tasks to be played back at a later time. At the start of each task the robot was in its home position. Subjects were requested to command the robot to move near an object, to pick up the object, to place it in a target area, and to move away from the object. To teach a motion which could be played back, subjects indicated key positions during the task by saying *Learn where it is.* After the motion was taught, the object was placed in its original location and the user's motion was played back to see if the motion was successfully taught. The number of commands to teach the task, the teaching time and any errors were recorded during each trial.

Task I was to move a cup (outside diameter of 2.25") to a large circular target (about 8" diameter). The target was eighteen inches away from the starting position of the cup and was in the same horizontal plane. Each subject performed nine trials of this task. During the first five trials, the user was asked only to pilot the robot to complete the task and was not concerned with teaching a motion for playback. During the last four trials, the user was required to teach the motion by saying *Learn where it is.*

Task II was also to transfer a cup, however, in this task the diameter of the target was reduced to 3". Each subject performed four trials. Task III was to transfer a magazine from a magazine rack to a bin. The target tolerance was about 3". The starting position and the target were separated by about three feet, but were not in the same horizontal plane. This task was repeated three times.

The three tasks were chosen for this initial evaluation to a get a sense of users' teaching abilities for tasks of varying difficulty. Based on the different demands for accuracy, Fitts' Law predicts that subjects would require the least amount of time to complete Task I (ID $\approx$ 3), and twice as much time to complete Task II (ID $\approx$ 6). We presumed that Task III would be more difficult and take more time than either cup transfer. The magazine was floppy and required fine manipulation to properly orient the gripper for grasp and object placement, and there was a large inter-target distance in more than one plane. However, Fitts' Law predicts that Task III (ID $\approx$ 5) would be easier than Task II and more difficult than Task I. We also assumed that the number of commands to teach each task would exhibit the same dependence on task difficulty as teaching time.

RESULTS

Figure 1 shows the results of Task I. There was large trial to trial variation, not attributable to learning effects. In general, the time required to teach the robot was slightly longer and took more commands than simple piloting of the robot. Playback took between one half and one third of the time required for direct piloting.

Of the 20 piloting trials performed by the four subjects, 5 were unsuccessful. Subject 1 had some initial problems understanding how to move the robot and failed in his first three attempts to transfer the cup. In the first two trials, the robot knocked the cup over and in the third trial, the user's commands caused belt slippage of the robot. Subject 2 also knocked the cup over during piloting, and subject 4 failed in one trial due to a speech recognition problem.

During the teaching trials of Task I, all subjects successfully moved the cup to the large target. Replay of all but one of the motions was also successful. The failure occurred because of an omission of *Learn where it is.*

Figure 2 summarizes the results for Task II. Of the 16 total trials performed by the four subjects for this task, 13 were successful for teaching and playback. On the average, subjects 1 and 2 used more time and commands to teach Task II than Task I, as predicted by Fitts' Law. In contrast, subject 3 showed no dependence on target size, and subject 4 took over a minute more for Task I than Task II.

Figure 3 summarizes the results for Task III. 11 of the 12 trials were completed successfully for both teaching and playback. Time to teach was highly variable and ranged from 4 minutes to almost 10.5 minutes for all subjects, while playback time was consistently around 1.5 minutes. Subjects 2, 3 and 4 required significantly more time (up to 4 minutes) and more commands (between 20 and 40) to teach the robot the magazine transfer compared with the transfer of the cup. Subject 1 also took more time to teach this task than either of the other two tasks (6.2 versus 4.7 and 5.3 minutes). However, he used only about 70 commands for this task compared with 60 for Task I and 80 for Task II.

Figure 4 summarizes the results by task and ID. Four subjects were able to teach the robot new tasks in a reasonable amount of time in 54 of the 64 trials (83 %). There was no significant difference in the time or number of commands between Task I and II, despite the doubling of the ID. Task III required about 2 minutes and 20 more commands than Tasks I and II. Playback time was independent of the task and ranged from 1 to 2 minutes. Subjects required between 41 and 100 commands to teach these tasks, and 1 command for replay.

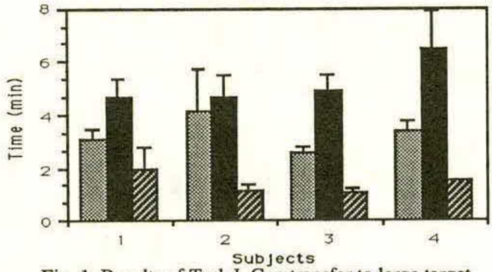


Fig. 1: Results of Task I. Cup transfer to large target.

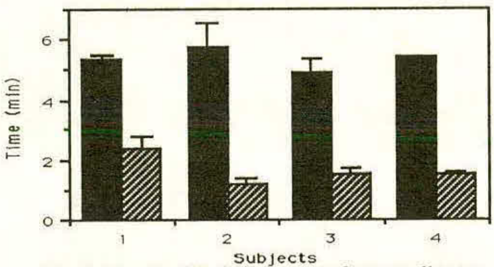


Fig. 2: Results of Task II. Cup transfer to small target.

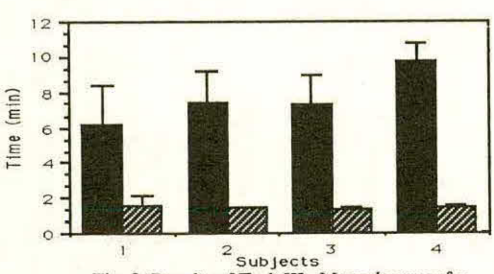


Fig. 3: Results of Task III. Magazine transfer.

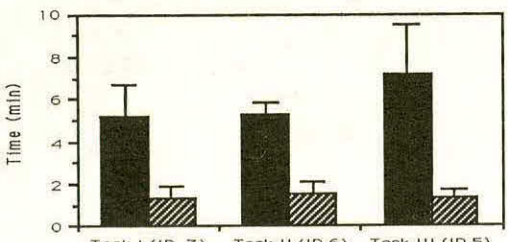


Fig. 4a: Summary of task time.

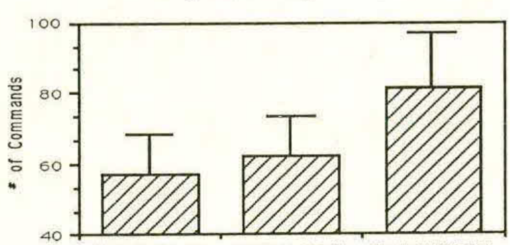
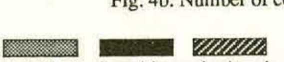


Fig. 4b: Number of commands to teach.



DISCUSSION

The results show that, for some tasks, users are able to instruct this voice-controlled robot. The additional time required to teach as opposed to simply pilot appears worthwhile. In a semi-structured setting, users will usually playback motions previously taught and only occasionally need to spend time teaching a new motion. This should increase independence by eliminating the need to call technical support to teach the new tasks.

An 83 percent success rate is promising. We have taken steps to improve this rate. Failures due to belt slippage are now prevented in a software stop. Some failures were due to poor initial training of the subjects. Although all subjects had a similar introduction to the system, subject 1 lacked a good understanding of the use of end point control until the last task. Further work should focus on the establishment and evaluation of a standardized training procedure.

Several of the failures were due to speech misrecognition. To improve recognition, we have since designed a new vocabulary structure which reduces competition among similar sounding words by increasing the number of vocabulary subsets and minimizing the active vocabulary in each subset.

The results suggest that Fitts' Law alone can not adequately predict task time or difficulty for voice-controlled, robotic manipulation. A more complete model of user performance should consider the properties of the objects, the robot work space, the user's learning curve, and speech recognition accuracy. If the user overshoots a target because of a misrecognition, it may take him several minutes to maneuver the robot to correct this error. Nevertheless, this may have no bearing on task difficulty. For a quantitative evaluation of a voice controlled robot, a more complete model of task difficulty and user interaction is needed.

FUTURE WORK

We anticipate performing an extensive evaluation to formulate a complete model of human/robot interaction during the teaching process. The model should provide an objective measure of task difficulty and predict teaching time.

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A FRAMEWORK FOR A PRACTICAL MOBILE ROBOTIC AID FOR THE SEVERELY PHYSICALLY DISABLED

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ABSTRACT

A framework for a practical, easy-to-use mobile robotic system which can allow severely handicapped people to control and interact with their environment is presented. Software written for a personal computer allows the user to command the robot to move about a structured indoor setting as well as to control household appliances. From within a control panel window, the user can command the robot joint by joint in a direct, teleoperator mode. Additionally, by creating a computer model of his surroundings, the user can direct the robot to move throughout the environment in a semi-autonomous manner. The robotic system adds a dimension of manipulative ability to a previously existing system designed to provide for the severely physically disabled person's needs of mobility, entertainment, and employment. Specifically, the robot is designed to perform simple pick-and-place tasks at table-top and floor heights under the user's supervision. Beyond its use as a domestic aid, the robotic system can serve as an inexpensive research tool.

INTRODUCTION

Several groups have been developing robotic systems as a partial alternative to paid human or trained animal assistants for severely physically disabled persons in domestic and vocational settings (1,2,3,4). University and industry sponsored projects have produced prototype aids in the form of voice activated, menu-driven robotic workstations. Such technology has been commercialized (5).

In the realm of mobile robotic aids, a prototype in which an industrial grade Puma 260 arm is mounted atop a custom designed omnidirectional base has been produced (8). The system presented in this paper offers advantages over such industrial grade systems in cost, portability, and overall simplicity while maintaining utility.

METHODS AND MATERIALS

The robotic system is composed of relatively inexpensive equipment designed for in-home use. Software is written in Object-Oriented Allegro Common LISP and runs on a Macintosh SE having 4Mb of RAM. A HERO 2000 robot was assembled from a kit and modified to extend its workspace to cover from floor to tabletop heights. Control of lamps and household appliances is via an X-10 Powerhouse computer interface module, which is interfaced to the modem port of the SE. An Esteem 9600 baud wireless modem augments the 600 baud radio frequency communications link provided with the robot, either of which can be interfaced to the printer port of the SE to allow untethered operation. A custom Machine Control Interface (MCI) has been developed for interfacing severely physically handicapped users to a variety of devices, including the SE (1). The MCI is made to emulate a mouse, allowing the user to control the cursor of the SE using head motion and breath action.

At the core of the robotic system is a set of software windows designed to translate cursor action into commands for the robot. The Teleoperator window has been developed for commanding the forward kinematics of the robot (Fig. 1). A combination of slider and buttons is assigned to each joint movement. A slider acts as a digital potentiometer whose maximum range is set to reflect the kinematic constraints of the joint, and whose output represents the desired amount of change to the joint angle. Joint activity is initiated and terminated using the buttons.

Robot inverse kinematics and semi-autonomous functions are commanded from within the World Modeller window, which displays a model of the robot and its environment (Fig. 2). As is done in commonly available graphics applications, the user constructs a model interactively using graphic primitives. In this case, the primitives represent real world objects such as household items, which are modelled both in form (physical characteristics) and in behavior (changes of state). Internally, the model is a 3-dimensional data base which can be accessed by a variety of procedures in commanding the robot to perform tasks such as gripper positioning, localization, path planning, and navigation in a world coordinate frame (6,7). The concept of generating commands for a real robot based on activity of a model robot is termed "model reflective command generation".

RESULTS

A first cycle of in-home evaluation of the robot began in March of 1988. A subject was given a written description of the system boot-up procedures and a brief demonstration of the Macintosh operating system, and without further assistance was able to command the robot in teleoperator mode using the mouse as an input device. His response to the system was favorable; he found the software easy to understand, and used the robot to move small objects around his apartment.

The robotic system has been demonstrated publicly on several occasions. Operation in the teleoperator mode was demonstrated at RESNA '87 in San Jose and SOAR '87 in Houston at NASA/JSC. Model reflective command generation was shown during

SOAR '89 at NASA/JSC. Path planning and localization routines have been tested in the author's office and adjoining hallway.

CONCLUSIONS

Relatively inexpensive robotic and computer technology is available which can be of use to severely physically handicapped people as well as to researchers interested in intelligent mobile robotics. New ways of simplifying the task of commanding a robot to do useful work have been developed using an Object-Oriented language, which provides a compact structure for representing the real world and for implementing advanced problem solving routines related to robot autonomy.

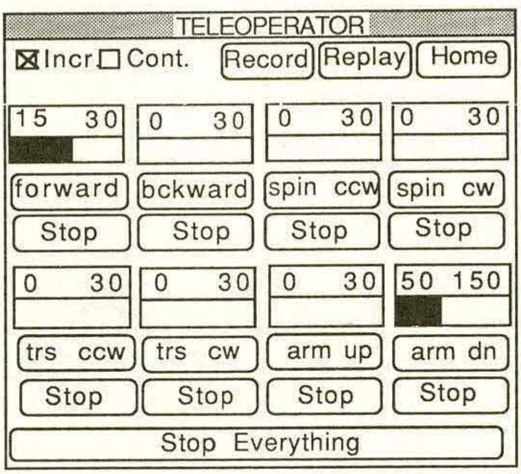

Figure 1: Teleoperator Control Panel

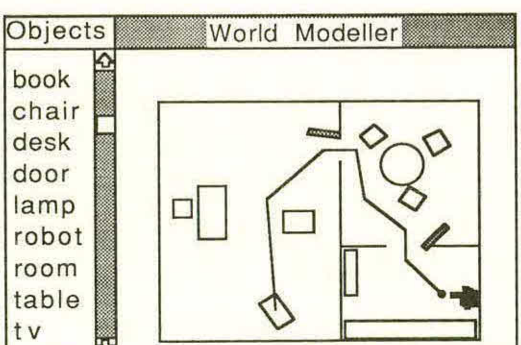

Figure 2: World Modeller and Path Planning

ACKNOWLEDGEMENTS

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A Voice-Controlled Robot System as a Quadriplegic Programmer's Assistant

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ABSTRACT

As part of an evaluation study in the use of robot technology to assist quadriplegics in the workplace, a senior analyst programmer has agreed to have us place a desktop robot system in his office. While the programmer is at his desk, the system effectively replaces all of the functions of his attendant. The system has been in place for three months, and evaluation is continuing. This paper summarizes the programmer's work situation, describes the robot system, discusses preliminary data, and projects the usefulness of such robot systems in similar work environments for severely disabled individuals.

INTRODUCTION

The disabled employee, RY, works four 10-hour days at his desk at a local utility company, Pacific Gas & Electric. He uses a voice recognition system to do keyboard emulation on his IBM-PC, which acts as a terminal to the company's mainframe. RY debugs and alters code, working in concert with a group of other programmers on projects. He employs an attendant full-time to provide daily living and vocational support.

The desktop vocational assistant robot (DeVAR), developed over the course of the past three years, consists of a PUMA-260 manipulator suspended on a four-foot horizontal track over the desk of the office worker. The robot accesses materials on the desktop and side shelving. It brings objects like papers to viewing racks, and objects like mouthsticks and cups of water to the disabled user's face.

For the evaluation period, the robot has functionally replaced RY's attendant. The attendant is staying on the job due to the experimental and temporary nature of the robot installation. The attendant is now used only to bring RY to his office from his van, set up the robot in the morning, and bring RY to meetings in other parts of the building.

BACKGROUND

RY is a C-3 quadriplegic, having injured himself in a fall five years ago. He worked at Pacific Gas & Electric for 9 years before his injury. The company retained him after his injury due to his expertise, supplying him with a Kurzweil voice recognition system to replace his keyboard. Using a voice recognition system is significantly slower than using a keyboard, but RY's productivity is not related to the number of lines of code written, but rather the effectiveness of his software design and debugging.

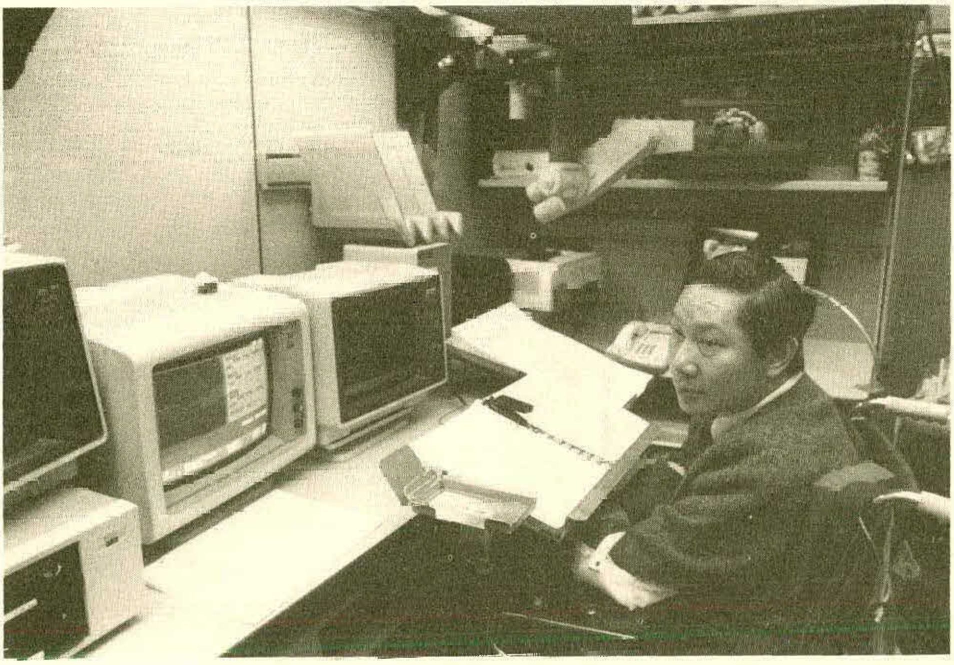

Figure 1. DeVAR-equipped Programmer's Workstation being used by test subject RY.

The DeVAR robot system is an outgrowth of a 10-year program of research and development. Initially, activities of daily living (ADL) were the primary application areas explored, but for three years we have concentrated on vocational support tasks.

The robot we have used throughout has been a PUMA-260 manipulator, an industrial manipulator with extensive safety features and a complete programming environment. The robot gripper is an Otto-Bock Greifer prosthetic hand, fitted with an optical encoder for finger position feedback.

The PUMA robot controller is supervised by an IBM-PC with a VOTAN board capable of voice recognition and digitized speech output. The board also lets the user answer the phone and place calls. We developed a user interface program, written in TurboPascal, to allow the user to operate the robot with simple commands. The system has been extensively tested in the clinic, and has been positively received by high-level quadriplegic test subjects [1, 2].

METHODS

To find test sites to be able to measure the effectiveness of the vocational assistant robot, we contacted employed veterans who were known to the VA Spinal Cord Injury Center, local organizations involved in training disabled people for programming positions, as well as large companies with a history of hiring severely disabled employees.

A local private school, Disabled Programmers Inc., collaborated with us for several months to enhance our user-interface program and establish a repertoire of robot tasks for severely disabled students. Tasks included the selection, handling and insertion of floppy disks and the presentation of reference manuals. The changes to our basic system made the next installation, in RY's office, a much easier task.

Prior to installing the robot in RY's office, the occupational therapist applied a standard functional assessment protocol to record RY's daily working habits for one work week. Subsequent analysis and discussions between the robot engineers and RY made it possible to customize the workstation to RY's own needs before moving the system to Pacific Gas & Electric Co. After installing the robot in RY's office, one month was needed to complete the revisions and transfer RY to daily use of the robot.

RESULTS

For the past 3 months, RY has been using the system for up to 10 hours per day, 4 days per week. The robot provides daily living support, including getting a drink of water, giving throat lozenges and medication, and serving a meal. Vocational support includes retrieval of a mouthstick; tearing off print-outs, presenting and storing them; manipulation of fanfold print-out stacks; and answering and dialing the phone.

Preliminary analysis of the history lists indicates that the robot is used to perform approximately 6 tasks per hour, requiring a total of 12 minutes to complete them. A comparison with RY's use of his attendant reveals that a person can do tasks approximately twice as fast as robots once the attendant is there in the same room.

In its current experimental state, the system requires maintenance weekly. These interventions are needed to refine robot task programming. Also on a weekly basis, one of the engineers upgrades the robot user interface software based on enhancements written on an identical DeVAR system in the clinic. The robot maintains a log of all commands used and all changes of system states in files known as history lists. These are collected weekly and analyzed by the staff for usage patterns, system problems, and possible enhancements to make the robot more convenient to use.

DISCUSSION

The installation of DeVAR in this work setting has been successful; however, the process of identifying robot tasks and of modifying an existing environment has proven to be difficult. Tasks are done differently by a robot than an attendant. Subsequent installations will be easier, especially with the increased robot repertoire and better understanding of the problems inherent in customization. Regular maintenance will be required for such installations. More robust task programming (for example, automatic calibration and checking for object alignment) and sturdier fixturing will be required to keep robot positioning inaccuracies from causing operational problems.

CONCLUSIONS

This first installation of DeVAR into a realistic vocational environment shows the potential for the replacement of job-site attendants by state-of-the-art technology.

The DeVAR robot system can support the daily life and vocational needs of a quadriplegic in a desktop office environment, and promises to do so cost-effectively.

ACKNOWLEDGMENTS

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THE HUMAN-MACHINE INTERFACE: A WORKSPACE-MOUSE CONCEPT

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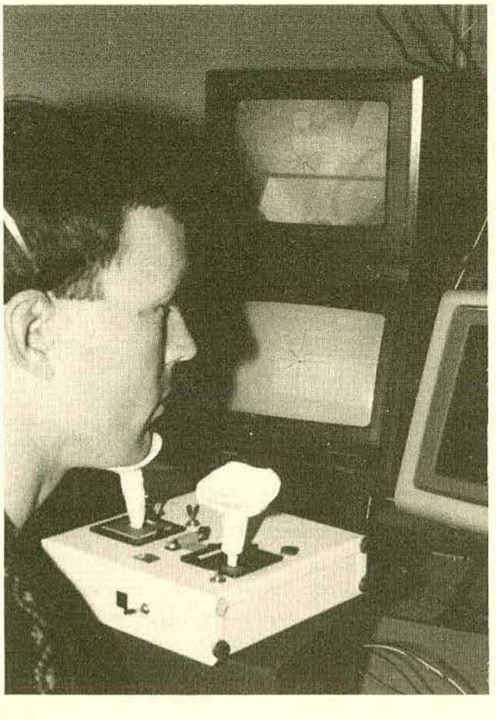
ABSTRACT

By extending the concept of a computer mouse to the three-dimensional case, a new class of human-machine interfaces is introduced. An instance of such a workspace-mouse system continues a trend toward transforming the role of the disabled individual from that of being a passive beneficiary to becoming an active employer of technologies such as robots and computer aided design systems. The goal is promoting functional independence for the disabled.

In particular, the workspace-mouse concept was demonstrated for a telerobotics application. The concept involves designating previously unknown objects and locations in unstructured environments for a mobile robot. A pair of remotely controlled cameras were mounted such that an operator using chin-joystick control could pan and tilt each camera independently. Verbal commands to a voice recognition unit such as "put that, and that ... there" were triangulated by the system into software code to semi-autonomously drive a nine-degree-of-freedom mobile telerobot.

Fundamentals of speed and accuracy for a workspace-mouse system are primarily related to human-machine camera pan and tilt step response characteristics to be described in a forthcoming paper(1). Adapting the concept of this workspace-mouse to the preparation of Computer Aided Design (CAD) drawings from workpieces or physical models, as well as other vocational, recreational, and daily living endeavors is a future focus of this research effort.



Operating a workspace-mouse: a triangulation algorithm locates an object when remote control camera crosshairs are aligned.

INTRODUCTION

Disabled individuals are gaining access to increasingly sophisticated technology to assist them. Humans in general, and disabled individuals in particular, however, are frequently required by system interfaces to function in an unnatural and overly technical way. In robotics, for example, unless exact object coordinates are known, a robot must be taken manually through a sequence before it can do the task autonomously. Similarly, in CAD drawing, unless precise dimensional literature is available, a human must use hand tools to measure the distance between corners on an existing workpiece or location of bends on a piping model.

More desirable, for the disabled in particular, would be an interface that allows users to stay at a relatively high supervisory control level while permitting them to interactively intervene at a relatively low object level. In other words, the human should not have to pilot a robot directly but should still be able to accomplish tasks involving new objects and locations about which the robot has not necessarily been informed. In the CAD drawing case, this means that the human should be able to point to corners, bends, and other features of a physical workpiece or scale model and the computer should be able to calculate distances and draw graphical representations.

The philosophy pursued in this research permits the human to perform functions that humans happen to be very good at, such as deciding what needs to be done and viewing cluttered visual scenes. The robot, on the other hand, is assigned to do what it does best, such as calculating nimble trajectories, avoiding obstacles, and coordinating all its own joint and wheel motions.

BACKGROUND

In 1986, the author programmed a PUMA 250 robotic arm to perform several routines including hair brushing, face washing, eating, drinking and tooth brushing for disabled veterans. The research effort was successful and became a basis for an evaluation project testing quadriplegics using a desk top robot with similar prepackaged routines(2).

Apparent, however, was that disabled robot operators should eventually be able to interactively reprogram the robot to do new tasks without having to hire a robot engineer each time items were moved or new tasks required. Verbal telemanipulation did allow some interactive fine tuning. In the eating task, for example, once the fork had been poised directly above the plate by the prepackaged part of the robot routine, the operator could say "down, forward, right, down" until the fork successfully pierced a morsel of beef stew. But new routines needed experts to help.

An interface that allows the disabled individual to simply say to the robot "go there", "put that there", or "that is the new mouth position" would enable customization for a wide variety of tasks. The user thus needed a pointing system to designate any location in an unstructured environment, and have the system itself derive the x,y, and z coordinates of the point.

METHODS

Preliminary testing of the new workspace-mouse concept involved six quadriplegics in a simulated environment with a one-armed mobile robot. While videotape recorders documented activities, the author manually panned and tilted a mobile video camera in accordance with head motions made by the test subject.

Subsequently, a workspace-mouse system was mounted atop the neck of a Puma 260 arm on an omnidirectional mobile base. The workspace-mouse system itself consists of two remotely controllable cameras spaced vertically apart by 20 inches inside a tower such that both miniature camera heads pan together but tilt separately.

At a remote console, where a pair of video monitors display the live camera views, the operator pans and tilts each camera to align crosshairs in the center of each monitor with an object or location. The coordinates of the point are then determined by triangulation when the operator gives a verbal command to a Kurzweil voice recognition unit. The operator drives the cameras using chin-cup joysticks on an Ace radio control unit similar to those used in flying model airplanes.

Optical encoders inside the camera tower measure the camera tilt and pan angles. This digital information, sent to a custom built controller board placed in the computer card cage inside the mobile robot, is used to determine the x,y, and z coordinates of an object when the operator verbalizes key words such as "that" and "there". Software converts verbal phrases such as "put that there" into a robotic routine with the correct matrix values for arm and base joint angles and wheel velocities for the entire trajectory.

The feasibility of head motion control, using ultrasonic head position sensors, was verified but the approach was aborted because a full range of camera velocities could not be reliably produced using the threshold level constraints implied by that technology at present.

RESULTS

The viability of the workspace-mouse system, as integrated on the mobile robot, was verified by several demonstrations. In one demonstration, miscellaneous items (a measuring tape, a spool of electrical wire, and electricians tape) were randomly placed in a work environment. An operator pointed to each via the two-camera workspace-mouse system and then to an open toolbox saying "put that, that, and that there". The robot successfully moved its base to appropriate way-points and it's arm to hover positions above each object, in turn, pausing only for final verbal corrections such as "down" or "right", and placed each into the tool box. Demonstrations producing similar results included palletizing randomly placed blocks on a wooden plate and putting a soda can and a wad of white paper into a trash receptacle.

Typical supervisory times for directing the robot to do these first-time tasks were: 54 seconds for putting three items in the toolbox; 71 seconds for putting four blocks on a pallet; and 35 seconds for throwing two items in the trash. Items were distributed within an 8' x 10' office cubical 6' from the robot on average and requiring camera rotations of up to 120 degrees (but not using the full 360 degree range possible). Accuracies to the initial hover position above each object were as predicted for the wide-field-of-view system ranging between 0.25 inches for objects less than two feet away to 4 inches for objects 10 feet away.

Detailed experiments now underway show that Fitts' Law applies to the workspace-mouse system as an instance of a human-machine system. The author's framework for predicting,speed and accuracy by deriving the parameters of Fitts' Law using control theory techniques will be submitted for publication in the near future (1).

DISCUSSION

The workspace-mouse concept has advantages over so-called autonomous systems. Besides allowing operation in unstructured environments, which autonomous systems cannot accomodate (by definition), the workspace-mouse concept replaces the normal off-line programming time with an interactive point designation phase that is generally much shorter. Since trajectories created by the workspace-mouse system can be stored for future use, the system provides an effective method of writing packaged routines as well as for performing one-time tasks.

The workspace-mouse concept requires less human supervisory time than telemanipulation because the human is only concerned with aiming a low inertia pointer at key locations instead of driving a large nine-degree-of-freedom robot through an entire trajectory. The workspace-mouse concept also enhances safety compared to telemanipulation. Because the planning phase is separated from the execution phase, human reaction time is elliminated from robot driving. The robot trajectory can be run quickly without concern for human control errors.

For adapting the workspace-mouse concept to the CAD drawing environment, the primary issue will be accuracy. Since camera spacing, object distance, and camera field of view are primary determinants of accuracy, the cameras should be widely spaced, the work piece or model should be close to the cameras, and the field of view should be as narrow as is comfortable from a human factors point of view. Zoom lenses would enhance performance when designation distances are great.

There are several other possible configurations for a workspace-mouse that are consistent with the concept envisioned by the author. A single camera with a laser or sonic range-finder, for example, might work well in certain applications, but the current two-camera system has the advantage that the operator can estimate the intersection point of the two camera lines-of-sight and designate points where there is no concrete object otherwise required for these latter configurations. A system with cameras spaced apart horizontally instead of vertically is virtually the same system as the one built for this project, however, such a system would have orders of magnitude higher inertia and would impose constraints on arm motion.

CONCLUSIONS

Pursuit of one or more applications of the workspace-mouse concept is recommended based on the positive results of this research effort so far. An evaluation study, in which a number of quadriplegics are tested with the workspace-mouse and telerobotic system, would be appropriate. Parallel to this, or alternatively, a research effort could be initiated to look at applying the concept to computer aided design and other applications where the ability to designate points in a three-dimensional environment might enhance the human-machine interface for disabled individuals seeking to use technologies otherwise beyond their reach for vocational, recreational, and daily living tasks.

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The Future of Microcomputer Applications for Young Children with Disabilities

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Abstract -- Microcomputer technology for young children with disabilities is briefly discussed. Suggestions for persons involved in planning comprehensive state systems of technology-related assistance are delineated in light of existing technology.

Introduction

Parents, teachers, therapists, and professionals in the rehabilitation professions share as a common vision the increased use of technology for persons with dsabilities to facilitate their participation in home, school, and community activities, *regardless of their levels of functioning* (Levin & Scherfenberg, 1987). However, despite the general level of acceptance of and interest in technology in our society, young children with disabilities are perhaps the least recognized as being amenable to the promise of technology. This is due, in large part, to the lack of information that has been disseminated relevant to technology applications for this population, the reactionary attitudes of persons toward the use of technology with young children, and the sluggishness with which technology transfer has occured (Cain & Taber, 1987).

Microcomputer Applications

The presence of a disability can indisputably limit an infant's ability to interact with the physical environment, negatively impact upon the development of optimal relationships between the child and parents, and contribute to a stressful family ecosystem. A variety of researchers in the past decade have demonstrated the potential of microcomputer applications for young children with disabilities. Such applications include teaching cause-effect relationships for very young infants (Brinker & Lewis, 1982a,b), communication (Behrmann & Lahm, 1983), and preacademic skills (Fleenor, 1985). Existing microcomputer applications have the capacity to quickly summarize information and display it graphically, providing information pertaining to the learning process that is publicly accessible. These developments are particularly significant in light of the federal mandate of P.L. 99-457, the *Education of the Handicapped Amendments of 1986*, and P.L. 100-407, the *Technology-Related Assistance for Individuals with Disabilities Act of 1988*.

In the former instance, language is present which implies the use of assistive technology such as microcomputers by the public schools in the development of individualized family intervention plans for young children, while in the latter, states may be provided with a funding base to develop comprehensive systems of technology assistance to *all* persons with disabilities.

While microcomputer technology is increasingly being employed in the nation's public school settings (Office of Technology Assessment, 1988), there seems to be little movement toward establishing innovative technology programming for young children with disabilities. This clearly suggests the importance of collaborative problem solving and decision-making regarding the use of these technologies. When such information is shared with parents, educators, and rehabilitation professionals--which is both desirable *and* mandated under existing federal statutes--considerable impetus toward an increased usage of microcomputer applications may be facilitated.

Interagency Coordination of Services

The IFSP of P.L. 99-457, as with the IEP of P.L. 94-142, is based on the concept of *future achievement*. Thus, it seems reasonable that all persons involved in the development of service strategies for young children envision the use of microcomputers when designing such plans. Even though the purchase of computers has risen dramitically in recent years, the level of use of technology for developing important competencies necessary for optimal function later in life cannot be said to approximate the level of usage of technology among community members in general. This may be due to a large extent to our preoccupation with the rigors of daily life, frequently resulting in the failure of personnel affiliated with service delivery models to design/authorize technology services that take into account the future of young children with disabilities.

An additional problem is that personnel entrenched in institutions of higher education continue to utilize practices which were learned in earlier college settings. Many times, information gained during the earliest college training experiences are used throughout one's life, modified only by training that may be received during the first few years following college. Similarly, changes in instructional practices at the college level are often time-consuming and costly to implement, resulting in considerable resistance to alerations in existing curricula. Unfortunately, it is at this level that some of the most dramatic changes in the degree of technology-related assistance mat be actuated.

In light of the increasing interest with funding ethics, *i.e.*, the decision-making processes relating to the dispensation of fiscal resources, persons in service delivery systems that target young children with disabilities will increasingly be called upon to explore interagency collaborative activities (*e.g.*, Kehr, Morrison, & Howard, 1985). P.L. 100-407 has provided the funding base for interagency planning of statewide systems of technology-related assistance, while P.L. 99-457 provides the potential funding for assistive technology such as microcomputers if they are deemed necessary in the IFSP.

In the process of planning state systems of technology-related assistance, the educational and rehabilitation communities must be active participants in order to fully address the needs of these children across all service areas. In Arkansas, for example, persons representing 25 different public and private agencies were involved in the P.L. 100-407 grant development activity. Extensive consumer surveys of infants and young children in this state, as well as of professionals who work with this population, were conducted. Data which were obtained reflected a number of important findings that have implications for other states seeking funding under P.L. 100-407. It was reported, for example, that a majority of children 0-5 years of age, or their parents/guardians, *needed more information* relating to technology in virtually all areas which were identified. However, the reported need for computers was three times that of children who were reportedly using such technology. A need was expressed for increased opportunities to purchase technology using credit-based systems, and greater opportunity to try out devices before purchasing them.

Professionals involved in service delivery to these children indicated that the greatest needs in the state centered around such areas as information dissemination, training, coordination of services, matching technology to the needs of young children with disabilities, funding patterns for technology, and computer usage.

This suggests a variety of potential responses for those involved in state service delivery planning:

- States should be encouraged to develop shared cost and service arrangements pertaining to microcomputers among agencies serving young children and their families, such as Public Health, Social Services, public schools, and Head Start. The federal and state governments should also remove varying eligibility requirements and other barriers to cost sharing for microcomputer technology services;
- States should work with the federal government to investigate incentives for private insurance and other third party providers enabling them to fully participate in the development and implementation of consumer-responsive technology service delivery systems which utilize microcomputers; and
- States should assess their personnel needs, certification, and licensing policies as they relate to persons involved in service delivery to young children with disabilities and their families. Funds should be made available to institutions of higher learning for the purposes of changing curriculum to address microcomputer and related technology issues, as well as the training of entrenched professionals to increase their knowledge base regarding microcomuters and their applications to this population.

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A SOUND-BASED COMPUTER SYSTEM FOR TEACHING BOTH BLIND AND SIGHTED CHILDREN

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ABSTRACT

Results of a technological research program are reported, the purpose of which was twofold: 1) to develop an educational tool based on sound with various applications in logic, mathematics, language and technology learning, 2) to create an adapted computer environment for use in classroom with both sighted and blind children. An IBM-PC compatible system was designed which is described here. Description focuses on 1) the sound model involved in this device, 2) hardware and software aspects, 3) applications.

INTRODUCTION

At school many activities for young children are designed to be seen: either different colored and shaped objects, printed exercise sheets or computer programs. Thus they are not accessible to blind children.
A technological project was put into place aimed at developing an educational tool based on sound with various applications in logic, mathematics, language and technology learning, in order to create a pedagogy based on sound, just as "natural" as traditionnal paper, paste and scissors pedagogy (1).
The concrete result of this project, which was conducted along with teachers, is an IBM-PC compatible system, including hardware and application software.

SOUND MODEL & TRANSFORMATIONS

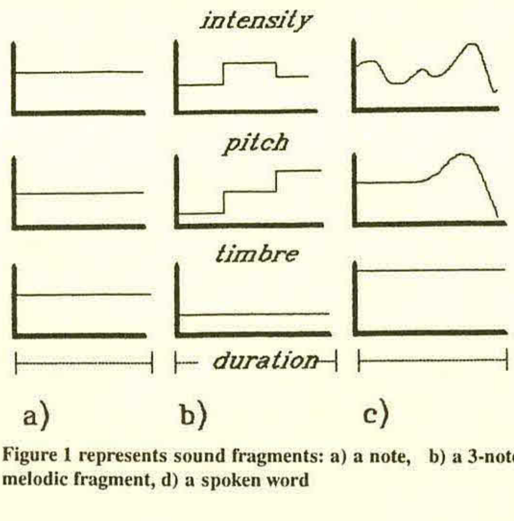

Figure 1 represents sound fragments: a) a note, b) a 3-note melodic fragment, d) a spoken word

The model used to control sound production considers the notion of "sound fragments" as being characterized by four different parameters: 1) duration 2) intensity 3) pitch and 4) timbre.
The latter three may be varied temporally. This quite simple model is readily accessible to young children. It can be applied to all sorts of sounds (fig. 1 a,b,c).
Firmware algorithms make it possible to transform a sound fragment, changing one of its parameters independently of the others.
From these fragments increasingly complex sound constructions can be built; these are "sound sequences" composed of successive or simultaneous fragments.

HARDWARE AND BUILT-IN SOFTWARE

Physically the system is a board, to be installed in a IBM-PC compatible host computer. Figure 2 shows its structure and points up its main functions. A Motorola 6809 microprocessor controls four types of functions: 1) Input of commands from the computer or from an external bar-code reader, 2) Output of data to the computer, 3) Interpretation and execution of commands, 4) Sound synthesis.

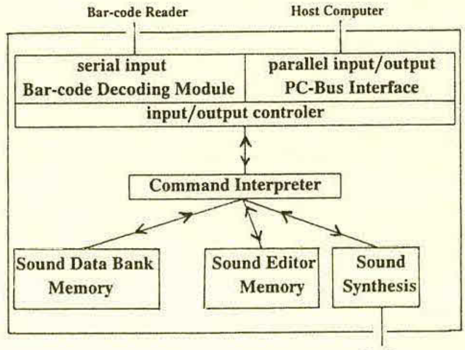

Figure 2 shows the block diagram of the sound-device

The command set can be used to a) load the sounds into the Sound Data Bank, b) edit sounds, selecting them and then deleting or tranforming them, c) emit sounds, d) save sound sequences from the Sound Editor Memory onto diskettes or disk.
Musical fragments can be produced in three independent channels by a General Instrument AY-3-8930 monochip. Thirty two timbres can be

memorized by the board. Noise and spoken fragments are produced in a single channel from a Philips RTC MEA 8000 monochip. They are precoded from real recordings.
All of these fragments are loaded from a disquette. Thus they may be renewed. For example, a 720 Ko diskette can contain about a half hour of speech or 250,000 notes.

CONTROL BY THE CHILD

High level software has been developed to allow both blind and sighted children to command the system.

Keyboard and speech synthesizer control. The child selects a command by navigating with the numeric keypad within a very simple tree-structured menu. A speech synthesizer provides information about positioning within the structure.
An alphanumerical keyboard can also be used to enter the commands directly.

Bar-code reader and command boards. Bar-coded cardboard sheets are provided to the child who can "read" them using a bar-code reader. For the blind, auto-adhesive strips show the location of the codes and serve as guides. They may also be used as Braille markers. Additionally, bar-code sequences can be used in order to build macro-commands devoted to specific exercises or games.

APPLICATIONS

Sound awareness and logic tasks. Prepared sound sequences are furnished. The children are asked to verbalize the differences between sound sequences. When they are able to discriminate sounds correctly, they may be asked to classify them according to several acoustic criteria.

Meta-linguistic training. We have devised a number of games which encourage the child to manipulate sounds according to a coherent plan through the use of the system's commands. For example a child may be asked to reconstruct a tune or a complete sentence from dispersed scraps of sounds (fig 3).

Programing activities. The technological aspects of the system can be accentuated which the child discovers through experimentation. When the system is used in this manner, it is an attractive way to introduce computer science.

FIRST RESULTS

Tested in several schools, the two proposed modes of command were proven to be realistic in a classroom environment for both blind and sighted children. Bar-code control has turned out to be powerful for use by children whose ages ranged from 6 to 9. Thus it could be a positive aid in implementing integrative activities.

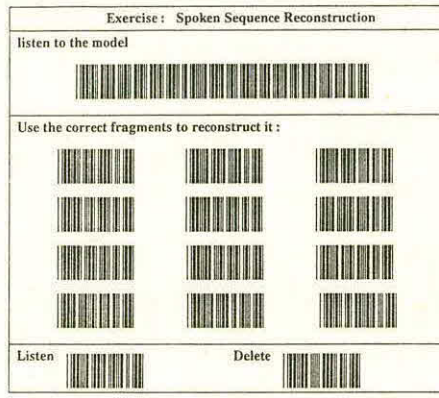

Figure 3 gives an example of an exercice to be solved using a bar-code reader

DISCUSSION

Since this approach (sound) to learning seems to be very attractive to young children, we are led to investigate its possibilities in learning situations more precisely. Although studies in this area are sparse, some indications can be found in two fields: teaching to visually impaired and pre-reading children. WOOD (2) observed in a visually handicapped population of children that listening abilities were greater than reading abilities. Studying children in kindergarten, Lundberg et al. (3) showed that phonemic awareness of spoken language was a strong predictor of reading and spelling skills.
These results seem to show the specific interest that such a sound-system could have. It could also be used as a flexible investigative tool for pedagogical research.

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Exploration of Simple EC Technology with Severely Multiply Disabled Students

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SENSORY STIMULATION CLASSROOM

This paper describes ideas that were developed while using simple Environmental Control (EC) technology with students, who are profoundly multiply disabled, and who attend a sensory stimulation classroom. Staff identified the students' needs and adapted the classroom environment, the toys, and learning materials to the students' abilities.

The school program is geared to severely multiply disabled students 6-19 years of age who are admitted for periods of 3 days to 5 weeks for interim or respite care, or for general rehabilitation. Students are in-patients in the hospital, receive services at the centre and attend the sensory stimulation classroom.

PROBLEMS

The most serious challenge posed to clinicians and teachers of severe multiply disabled and non-speaking children is: to engage students in meaningful and/or fun activities. No matter how highly qualified or how enthusiastic, staff working with these students become frustrated by the students' inability to make things work and by the students' lack of success. Most of the students were limited because they could not move or reach, did not see, had great trouble orienting themselves, and were very limited in their physical gross and fine motor movements. The students did not react with interest to 'traditional' toys. Staff were encouraged to experiment with various kinds of technologies in connection with play and learning materials. Some of what was constructed used no technology to speak of and other applications used basic technology. A simple Environmental Control (EC) unit consisting of an Ultra 2T transmitter and two power modules was used to operate a tape recorder, radio, electric train, or battery operated toys.

PRACTICES

It was observed that **toy placement** is important. Toys should be located such that the child can easily see, hear and touch the toys (when it is safe to do so). It is very important to **arrange the situation** to **ensure success**. Before starting the initial session; all switches and toys/appliances should be tested to ensure that they work. A non-functioning toy will cause tension in the teacher which will invariably be picked up by the student and cause different degrees of anxiety. Regular sessions or **set routines** into which the switches and EC activities are integrated can help to establish a **pattern of expectations** on the part of student and teacher. Even the simple practice of working with a student for 15 minutes per day appeared to establish a basic "work framework".

PROCESS

Most instances of sensory technology provide opportunities for communication and the very important social component. The presence of social interactions of student and teacher or other facilitators is often crucial to the success of the technology. It was noted that the switches, toys and appliances create a **shared context** for the teacher and the student. As students become able to control things, they acquire a real stake in the EC situation. This enhances realism and this interactive discourse of student, teacher, and technological-device-that-is-relevant-for-the-student fundamentally changes the nature of the teacher-student interaction. When, in more traditional sensory stimulation environments, a teacher or caregiver works with persons who are severely multiply disabled and nonspeaking the interaction between teacher and student is often one-sided and appears incomplete. The toys and switches can give a new substance to this relationship. The technology gives the teacher something to explain or talk about, the student something to act upon and look at, and both something about which to be excited. As a consequence, the interactions can be sustained longer and can be more rewarding. It is clear that all involved, pupil, teacher, or Teaching Assistant, could benefit from this effect of sensory technology. Whether technology plays the role of a facilitating tool or a prop in bringing about a more sustained relationship between teacher and student is an interesting question. But, no matter what the answer to this question is, the motivating, interaction enhancing effect is real and very positive.

SIMPLE TECHNOLOGY

Most of the toys or appliances that our students used were operated via Ultra 2T Environmental Control (EC) units. The EC units allowed the student to turn a device on or off with a switch although the appliance used standard electricity. We found that our students had definite preferences for particular materials. Some responded only to a tape recorder and music and not comfort tapes (i.e. audio tapes with a spoken message from mother). Some preferred an electric train as well as music on the tape recorder but showed no interest in an electric fan. Some would have nothing to do with the train or fan but showed some interest in the music and in a motorised mother dog with her puppies. Very few students were interested in a little bear pounding on a metal drum.

Occasionally, students displayed disruptive and/or self injurious behaviours and we found that toys/appliances activated by switches did at times distract them from these negative behaviours and could be used as a reward.

TABLEAUX VIVANTS

We recently developed a 'big story book' called THE LITTLE TRAIN that is intended to provide a structure for engaging several students in an interactive activity. Specific subgoals were to: (1) encourage participation; (2) encourage practice in communication through choice making; (3) operate one or more switches in the context of a partially enacted story; (4) encourage students to be more responsive to each other; (5) create an opportunity for students to perform for an audience.

The Little Train "big story book" is a 60 X 100 cm ring bound book with hand written text adapted from the well known books "The Little Engine that Could" by Watty Piper and "The Perky Little Engine" by Margaret Friskey. Artwork for the book was provided by David McAlese. The story was designed such that the book could be read to a small group of students, or a small audience. Students can participate in the story by operating a switch at appropriate times during the story. The switch can start and stop the train and produce sound effects via the train. Lights on the track can be controlled by a switch and it is possible to incorporate a slide projector with story related background material or scenery. With this technology these severely multiple disabled students can for the first time in their lives perform for an audience.

IS TECHNOLOGY A USEFUL TOOL

To sum up: We have found that technology has been a useful tool in our work with this student population of profoundly physically and developmentally disabled students. It is true that each time we developed some new materials, we tended to view these either too sceptically or too enthusiastically. While some of the students did respond with interest and curiosity to some of the adapted materials, other students showed very little or no response at all to the materials that we thought would become immediate favourites with them.

WHAT DOESN'T WORK

In the course of two years' work with a population of severely multiply disabled students we found that **what does not work** are activities that:
- are too repetitive
- elicit very little language from staff
- are essentially simple cause/effect: it goes on/it goes off
- have no sense of humour
- have minimal movement
- have no story line to expand on
- produce an unpleasant noise
- startle rather than soothe
- have no human component

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ENABLING TECHNOLOGY IN THE UNITED KINGDOM: REPLICABLE PRACTICES AND PRODUCTS

14.4

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Introduction

International cooperation and information exchange between professionals has the potential of improving the education and lives of individuals who may benefit from enabling technology.

In the summer of 1989, the director of a state-wide information and demonstration center on enabling technology, funded by an IDEAS grant from the World Institute on Disability, visited the Aids to Communication in Education (ACE) Centre in Oxford, as well as several other similar centers in the United Kingdom.

Discussion

A major focus of the study visit was to investigate products, in present use or under development, which had the potential of replicability in the United States. A number of products which have no direct counterparts in the United States were discovered. A description of these products follows:

The MicroMatrix Headband developed by Clinical Engineering Designs holds a headstick or small light pointer. The MicroMatrix units are light, cool, and adjustable by screwdriver. The Lightpointer, which is powered by rechargeable batteries incorporates a beam which remains the size of a Bliss square regardless of distance.

The Chin Switch System mounts on a chest plate and accommodates up to four chin switches. Switches are adjustable; the chest plate provides stability to the system.

Modular Switches developed at Chailey Heritage Hospital consist of a set of hand operated switches which can be configured in a linear or angled arrangement. The modules, which connect together, provide customization and demarcation between switches.

The Necklace Switch also developed at Chailey is comprised of switches in the form of beads mounted on a thin collar worn around the neck. Beads available in different sizes may be arranged to meet individual and task requirements.

The Plocka Software program, a flexible authoring tool for teachers, is designed for use with single switch users. Developed in Sweden, the ACE Centre will field-test this software in a Head Injury program.

The Persona Communication Device is presently in development at the Sandwell Communication Centre. An inexpensive and small augmentative communication device, the Persona provides excellent voice quality and logical letter coding.

The AVOCA Communication Device, developed in Belfast, Ireland, stores speech and word processing data on a solid-state memory card. Accessed through a variety of methods, the devices includes built-in calculator and word processing capability.

The Communication Tray developed at the Musgrave CAC in Belfast, N. Ireland, incorporates airplane hinge technology and a persplex tray.

The presentation will include a slide presentation of enabling technology centers in the United Kingdom, augmentative communication and adapted input/output devices presently being used in the United Kingdom, and those in development.

Acknowledgements

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ELECTRONIC DEVICES FOR SPEECH THERAPISTS

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ABSTRACT

The Institute has been developing several devices for use by speech therapists. The devices described here include communication aids, drooling therapy aids, and assistive devices for education. Each device has been developed in response to a need identified by a speech therapist, and clinical trials have indicated that the devices are worth developing further.

LIGHT RING

Children with visual handicap naturally have trouble focussing the attention on a given object for a useful length of time for speech therapy. The Institute has designed a flexible ring of bright lights, safely encased in a plastic tube that can be wrapped around an object in order to draw a child's attention to it (Fig. 1). The batteries last for several hours, each ring of 70cm length being turned on and off by an internal switch. Rings can be joined together to form a continuous length of tubing. The batteries are recharged by plugging the ring into a charger supplied with the device. Clinical trials with paediatric speech therapists have had good feedback, and further development is under way as a result.

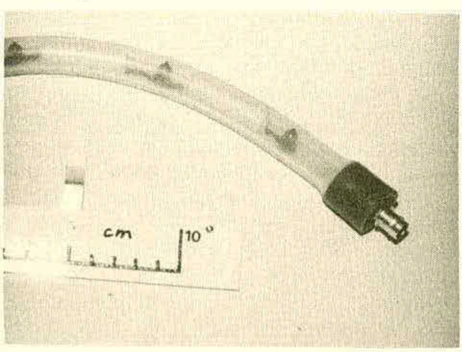

Fig. 1. Light Ring, a flexible, waterproof ring of flashing lights

SELECTION BOX

There are many available communication aids that function by allowing the user to cycle through a series of lights with associated pictures. The picture that is selected shows what the user needs or wishes to communicate. However, the devices available at present are all overly complicated for many applications. We have designed and built a simple and cheap version of these devices, that allows the user to touch the picture or cycle through the pictures with a single remote switch as preferred. (Fig. 2). A sound reward is triggered when a picture is selected.

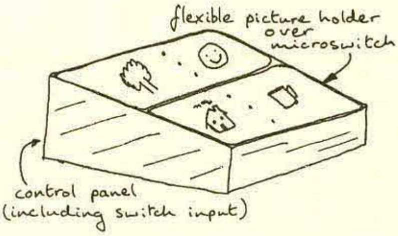

Fig. 2. Selection Box, picture selected by touch or switch closure

ORAL SUCTION PUMP

A temporary measure for a person with very severe drooling problems is a pocket sized suction pump and reservoir. A tube is taken from the reservoir to drain the mouth when necessary, or continuously if required. Using an enteral feeding pump, a prototype has been constructed to assess the possibilities of such a system, and has been used under the care of a research speech therapist. We now have our own design of pump system that is cheap enough to be widely available, and small enough to be easily transportable. A saliva reservoir attached to the pump unit is easily removed and cleaned.

SPEECH LOGGER

When having speech therapy, people often have very little idea of how much time they spend vocalising during everyday life. The speech logger is a portable device that triggers a timer whenever the wearer vocalises (Fig. 3). The total number of hours (to one decimal place) is displayed for the user to have quantitative feedback on their use of their voice. In order to prevent erroneous resetting, it is only possible to reset the count by removing and reconnecting the battery. An ordinary PP3 battery lasts for a month of continuous use.

SWALLOWING AID

People with a mental handicap often have difficulty remembering to swallow regularly, and the dribbling that results makes social contact embarrassing. A small device has been developed (Fig. 4) that gives a regular sound reminding the wearer to swallow, in the hope that the wearer will gradually develop a swallowing reflex. The device is lapel worn and has been decorated as a badge or brooch, according to the user's preference. Power is supplied by a single watch battery that gives over two months' continuous use. The trials have been very promising, and clinical data is now being collected for a quantitative assessment of the device's use.

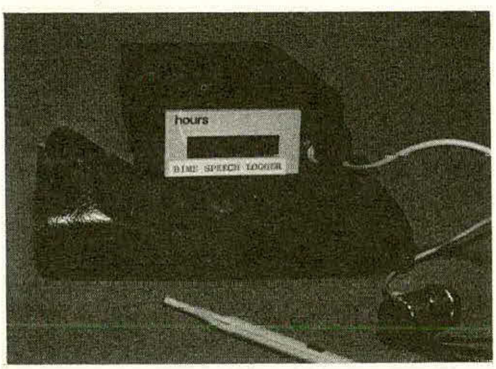

Fig. 3. Speech Logger, displaying total no of hours spent vocalising

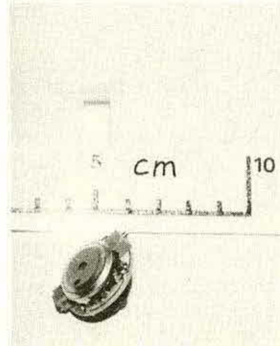

Fig. 4. Swallowing Aid, lapel worn, reminding wearer to swallow

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A Human Factors Approach to Adapted Access Device Prescription and Customization

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INTRODUCTION

Typically clients taking part in adapted access programs are prescribed hardware and software computer adaptations which are then customized to suit their specific abilities and needs. Device prescription and customization is often a complex procedure. Little is known about the qualitative and quantitative properties of adapted devices. There is, however, available in the human factors domain a body of literature that is highly relevant and that may facilitate this evaluation process. Human factors is defined as the systematic application of information about human abilities, behaviors and characteristics to the design and evaluation of objects, equipment, and environments[13]. To date, research in this field has influenced the design of man-machine interfaces and workspaces[13].

The objective of this presentation is to show the relevance of human factor design criteria to adapted access prescription and customization. This will be accomplished by (1) presenting data from the literature that demonstrates the importance of five selected design criteria and (2) using case studies to illustrate their clinical applicability.

(1) DEVICE PLACEMENT

Device placement has a considerable influence on the upper extremity postures required for device operation. Experimental results based on videotaping[3], visual observation[10] and EMG recordings[12] have consistently documented that postures adopted by typists have negative biomechanical and physiological consequences. The primary deleterious effects were excessive strain on the pronator muscles and ulnar deviation [1,10].

Lateral tilt and frontal slope of the keyboard were two approaches used to correct these inadequacies. When laterally tilting the keyboard, user key press frequency and error rates were not affected, although endurance improved[10]. Other studies had opposite findings[4]. Furthermore, standard keyboards were sloped at 30 degrees [1,12] yet subjects indicated preferences to keyboards sloped between 14 and 25 degrees[14]. Measures of productivity were not influenced by manipulating numeric keyset slope [14].

The case of GL a C5-6 quadriplegic illustrated the importance of device positioning. GL accessed a keyboard with two hand sticks affixed with universal cuffs. The keyboard was sloped (-45^0) in the frontal plane to allow for an improved view of the alphanumeric layout. The keyboard slope also provided a mechanical advantage that facilitated key strike.

(2) ALTERNATION OF HANDS AND DIGITS

Video-taped observations identified that proficient typists maintained digits in constant motion so as to promote overlapping digit movements[3]. Such movements are preferable, as there is a shorter time interval between keystrokes, diminished duration of key contact and reduced key activation force[8,11]. Single digit typing is the slowest for each keystroke is made in sequence[3].

In the light of these findings it was recommended that the alphanumeric layout be reorganized and that typing techniques be taught to encourage hand/digit alternation[11]. The standard keyboard layout does not exploit the advantages to be had by alternating hands[6,8] whereas the simplified Dvorak layout promotes this design criteria[8].

Alternation of hands proved to be useful for JA, a 19 year old with spastic diplegic cerebral palsy. Using her left hand, JA could achieve a functional rate of data entry. Her right hand was capable of some functional movements and it was therefore beneficial to promote alternation between hands and thus encourage overlapping typing. A one handed typing technique whereby the left hand is predominantly responsible for alphanumeric input and the right hand for the space bar and enter key was therefore prescribed.

(3) DIGIT TRAVEL

Minimal digit travel appears to be desirable for more efficient keyboard usage [16]. Rearrangement of the alphanumeric layout to promote home row typing or clustering more frequently used characters in the center of the keyboard are two strategies used to achieve this goal [2,16]. Other approaches include innovative keyboards such as the miniature or chord keyboards.

Subjects using an alternative (Dvorak) layout, which had a significantly larger home row vocabulary[3,6], demonstrated no difference as compared to the standard layout[8,15]. Although centering common characters was postulated to be more efficient for hand stick users, further research is needed to confirm these findings[2]. Center weighted layouts in conjunction with reduced sized keyboards could also minimize digit travel. Chord keyboards are a distinct strategy for reducing digit travel. Chord keyboards when compared to the standard produce higher rates of input [7,9] and are suitable for children with CP as well as clients with muscular dystrophy[9].

SV, a 23 year old male sustained a C5–6 spinal cord injury as a result of a fall. He used a stick and cuff method of access and was prescribed a mini keyboard. Fine distal stick movements were controlled from shoulder girdle musculature and the miniature keyboard aided to minimize movements thereby reducing travel time. The small size of this keyboard eliminated extensive compensatory postural adjustments which were problematic for SV.

(4) DIGIT LOADING
In addition to minimizing finger travel it is desirable to have each digit loaded in proportion to its strength and skill[6]. Indeed the standard layout overloads the forth and fifth digits [6] whereas an alternative layout has a superior distribution of digit loading[6].

This design criteria is relevant for individuals whose digit strength does not necessarily diminish towards the more ulnar digits. Such is the case of MM who as a result of systemic lupus erythematosus and scleroderma developed severe arthritic deformities (i.e. ulnar deviation and boutonniere contractures). MM required a data entry device for graphic programs and was advised to use a trackball since operation would require only small motions of the 2nd, 3rd, 4th, and 5th digits. Graphics tools would be selected by small isometric contractions of the thumb flexors. This access method was recommended to minimize digit movement and loading and thus limit the development of additional arthritic deformities.

(5) MECHANICAL CHARACTERISTICS OF KEYS OR SWITCHES
Few formal standards have been established for individual key/switch characteristics[1]. Keys are typically 1.3 cm in width, and require 0.7 to 1.6 cm of displacement for activation[1]. Alternatively adapted switches may range from 1.2 cm to 8.7 cm in size and 0.004 cm to 0.1 cm[17] of displacement. Typical key activation forces range from 0.6 to 2.2N[1] whereas the range for adapted switches is 0.3N (membrane switch) to 4.6N (cup switch) [17].

Varying key characteristics when subjects typed on push–buttons set had no influence although increasing key top size reduced key press time and decreased errors[5]. These improvements should be accepted with caution since letter size also increased[1].

RS, a 32 year old male with amyotrophic lateral sclerosis is completely dependent and non–vocal. Two switch morse code was prescribed for RS to access a computer. The PIP and DIP joints of the 3rd and 4th digits on both hands can be actively flexed (-90°) against gravity with some resistance but the segments cannot be returned to the fully extended position when working against gravity. Given RS very limited movements, switch characteristics (compliance, displacement, and size) played a extremely significant role in device prescription[17].

CONCLUSION
These design criteria are only some of the issues to be considered for adapted access device prescription and customization. In order to fully exploit residual abilities of physically disabled individuals abbreviation expansion and word prediction techniques should be used as well.

Human Factors is a discipline that provides a substantial theoretical basis for design of work spaces, equipment, and tools[13]. The application of this theory to the field of adapted access would greatly enhance the prescription and customization of data entry devices. It is thus timely for rehabilitation specialists to increase their knowledge in this domain to promote more efficient adapted device usage.

ACKNOWLEDGMENTS This work is supported by the NSERC. S. August is funded by a MRC studentship.

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ON-LINE EXPERT SYSTEM SUPERVISOR FOR A WORKSTATION FOR THE PHYSICALLY DISABLED

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ABSTRACT
This paper describes the development of an "on-line" voice controlled expert system to assist people with severe physical disabilities, but who have limited speech capabilities [1,2]. The expert system helps perform tasks which otherwise are not possible due to a person's physical disability. This paper describes the expert system which integrates various subsystems in a computerized workstation and monitors and controls their application. The subsystems monitored and controlled by the on-line expert system include a telephone, a robot, an electronic door opener and various appliances.

METHODS
The Texas Instruments PC Consultant Plus and PC-OnLine were the expert system shells used to build the expert system [3]. PC OnLine was used due to its ability to perform real time operations. When active, the expert system operates in a supervisor mode, maintaining information on the activities and status of the entire workstation [4].

The expert system accepts spoken phrases as input and accordingly controls the subsystems (and devices) in the workstation. This was accomplished by integrating into the expert system application the Texas Instruments TI-SPEECH board and software.

The control of appliances was accomplished by integrating the X10 Powerhouse system into the expert system. The X10 system can turn on and off lights and appliances that are plugged into the electrical outlets in a home or office. The objective of this subsystem was to help a person with limited mobility to control devices in their home or work environment. A wheelchair-bound user could open or close doors by simple speech commands.

The expert system also was programmed to remotely control a set of tasks that a robot could perform. A Heathkit HERO robot was pre-programmed to perform a set of tasks such as checking the temperature, finding and retrieving an object and carrying an object from one location to another. The robot uses its own senors for temperature, light and distance measurements.

Through the on-line expert system, a user can command the robot to perform any of its pre-programmed tasks. While the robot is conducting its task, the expert system returns control to the user who can specify another task for the system to perform. This provides virtual multi-tasking capability to the workstation [2].

The expert system also integrates the TI-Phone Management option as a subsystem of the workstation. Using this subsystem, a user can place phone calls using simple voice commands. The workstation's computer also serves as an automatic telephone answering system. This subsystem provides a user who has limited or no limb usage the ability to use the phone by voice commands. In addition, a user with a learning disability can place a call by simply stating the persons name. The computer automatically finds the number from its database and dials it.

RESULTS

On-line expert systems technology has been applied to build a versatile integrated computer-based work environment for physically disabled individuals. This environment allows individuals with limited voice capability, regardless of disability, to monitor and control physical conditions and perform electronically or telephonically (voice/data) driven tasks.

All these workstation tasks are continuously monitored "on-line" by the expert system supervisor which operates under the spoken command of the user.

DISCUSSION

The voice controlled expert system described here represents a unique application of on-line expert systems technology, combined with speech recognition and phone management technology, to provide solutions for a real life problems.

The system implements a simple human-machine interface, with technology that is "transparent" to the user, in a versatile workstation which serves human needs. This application is another step towards the development of affordable applications using advanced technology in the field of rehabilitation engineering.

Since a picture is often better than a thousand words, a video tape will be presented which shows the system in operation.

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DIRECT MANIPULATION OF TEXT BY SCANNING

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ABSTRACT

Current transparent alternate access systems are inadequate for someone using a scanning system to operate a direct manipulation interface. Emulating the actions of a pointing device through scanning reduces the directness of access and increases the complexity of interaction. This paper explores an alternative approach which emulates the task that the pointing device would otherwise perform—selecting a point or a block of text. A prototype scanning system has been designed that directly scans the text as a selection set of blocks.

INTRODUCTION

In the past decade, research into computer access for people with physical disabilities has focused on "transparency." A transparent approach replaces the standard methods of input to a computer system without otherwise affecting the system's operation. Transparent alternative input can penetrate to various levels of the system: the physical input device, the software driver which translates signals from the device, or the user interface which receives information from the driver.

The most common transparent approach, replacing or emulating physical input devices while leaving the user interface unchanged, has been effective until recently. In graphical user interfaces (GUI) such as the Apple Macintosh,™ Microsoft Windows,™ and IBM Presentation Manager,™ direct manipulation has become the dominant style of human-computer interaction, and a mouse supplements the keyboard (Brownlow et al, 1989ab). Transparent emulation of the keyboard to input text is still possible, but mouse emulation is not always functional.

To provide full input capability to all users, it appears necessary to replace the user interface. Yet an alternative must retain the power of the original direct manipulation interface. It must give direct access to data displayed on the screen and permit efficient manipulation of the data through brief, intuitive sequences of actions. This paper describes an attempt by the authors to meet this challenge, exploring the use of a scanning system to edit text.

SCANNING AND DIRECT MANIPULATION

An inherent problem with keyboard emulation is that the user must deal with both the emulating keyboard and the interface associated with an application. In a GUI, these can conflict. While a visual keyboard may employ scanning, for example, a word processing application's direct manipulation interface usually requires pointing. There is no easy way for the user to select menu items or to select text for editing within the application's work area.

For users who can operate pointing devices, it is possible to integrate an alternate access system with the standard user interface. In a GUI, one window may hold a visual keyboard and another the application. A pointing device can be used to select text and menu items as well as to enter information via the visual keyboard. Users who can only scan, however, will be restricted to text input.

Menu items can be made available within the visual keyboard. If equivalent keystrokes exist for every menu item, they can be mapped into selection set items. Otherwise, macro definitions of mouse movements to select each command are required. It is feasible, but not practical, to emulate mouse movement with cursor keys in the visual keyboard. The resulting interaction method would be grotesquely cumbersome: repeated scanning to select cursor keys to move a screen pointer to a menu and then pull it down, followed by more scanning to move the pointer to reach a command.

Selection of chunks of text for editing poses an even more daunting problem. Here, the user must position the pointer to indicate insertion points and to mark blocks of text for editing (e.g. cutting, copying, pasting, and formatting). In addition to incorporating cursor movements as selection set items within the visual keyboard, a typical solution is to include block actions (e.g. selecting the next or previous character, word, sentence, or paragraph). The disadvantage of this approach is that it requires the user to make repetitive selections of movement items while shifting attention between the text within the application and the visual keyboard. Between selections, the user must decide what command to choose next. The result is slow, awkward interaction prone to errors in proportion to the many selections made. In no way is the user directly manipulating the data.

A POSSIBLE SOLUTION

The authors are exploring an alternative approach that applies the user's scanning technique to the body of text in the application work area. With this method, a user no longer has to select cursor or block movement commands within the visual keyboard. Blocks of text are selected like any other item: the blocks become a selection set.

Although the underlying ideas are rather simple, working out their details is more difficult. In order to experiment with various concepts without being constrained by an existing user interface, the authors have been developing a very limited prototype of a scanning text editor.

Scanning Sequence

Figure 1 illustrates the progression of scanning; from paragraphs to sentences, words, and finally characters. Since a word processor is most often used for natural language, the sequence of scanning follows the structure of language rather than some arbitrary hierarchy of units. In the single-switch prototype, the scanning of text blocks proceeds automatically until the user activates the switch. At this point the scanning pauses at the current block, and the user can activate the switch again to stop the scanning and select the block, or let it continue within the current block, through blocks of the next smaller size. (A second switch could also be used to stop the scanning.)

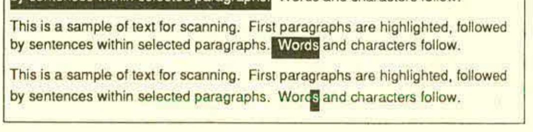

Figure 1: Scanning through successively smaller blocks of text.

Text Selection Method

Two modes of selection are involved in working with text. The first kind sets the insertion point for subsequent typing, and the second chooses a block of text for editing. There are two main techniques for implementing these selection modes. In a standard pointing interface, the user points to a character position to set the insertion point, and drags from one position to another to highlight a block. A scanning interface can mimic this method. The user scans through the text to select an insertion point; to choose a block starting at that point, the user makes a command selection to enter a special extension mode, then scans to the end point of the block. This approach is somewhat awkward, since the user cannot directly select a block.

A more powerful method takes advantage of the nature of block scanning. The user can stop the scanning at any point in the block hierarchy and select the current block. Without having to define both beginning and end points, then, the user can select text for editing in the standard block sizes. Thus individual paragraphs, sentences, words, and characters can be directly selected. All editing functions are immediately accessible. Having selected a block, furthermore, the user can also choose to set the insertion point: before the block, over the block (so that further typing will overwrite it), or after the block.

Editing Functions

When the user stops the scanning, the system displays a keyboard of editing functions (Figure 2). Icons indicate the various possible actions. Before scanning through this keyboard, the system pauses and waits for a switch activation. Experience with the prototype indicated the need to pause and allow the user time to consider.

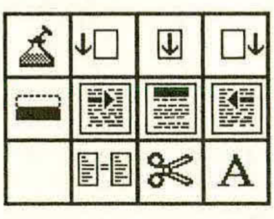

Figure 2: Block editing keyboard.

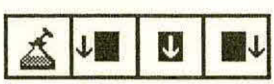

Figure 3: Block editing keyboard with insertion points modified to paste text.

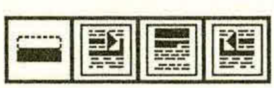

Figure 4: Block editing keyboard with scanning modes modified to extend text.

The rightmost three icons in the top row have dual purposes. Normally they allow the user to set the insertion point before, over, or after the selected block. The first, "glue pot," icon modifies the function of the other three. Their modified functions are to insert, or "paste," the contents of the clipboard at the respective locations. The icons are redrawn to indicate their changed functions (Figure 3). Selecting the glue pot again toggles the modification off. After placing the insertion point or pasting text, the block editing keyboard disappears and a standard alphanumeric visual keyboard is displayed and scanned for text entry.

Like the first row, in the second row the first icon modifies the rightmost three. The latter select one of three text scanning methods: forward locally, forward from the top, and backwards locally. Normally these methods scan the text for a new block; when modified, they extend the original selection to highlight a block of nonstandard size. The icons are redrawn to indicate the changed mode (Figure 4). Once a scanning method is selected, text scanning begins.

The icons in the third row respectively copy and cut the selected block to the clipboard, and format the selection. After the user chooses copy or cut, the system re-scans the block editing keyboard to select an insertion point or a scanning mode. The format icon calls up another keyboard for choosing formatting features such as text font, style, size, and alignment.

Within the alphanumeric visual keyboard, the selection set is continually scanned so the user can enter multiple text items. To move the insertion point or edit the text, the user switches back to text scanning by choosing a scanning method icon as in the block editing keyboard. To move the insertion point a few characters, it is easier to use the direction arrows that are also provided in the visual keyboard rather than scan the text.

CONCLUSIONS

The author's explorations of direct manipulation through scanning have resulted in a prototype text editor that appears to surpass the efficiency and functionality of a typical transparent access system. The block scanning and selection method described above provides direct access to text, allowing the user to position the cursor or edit a block quickly and efficiently.

Field testing of the prototype is underway. The next stage of development is to investigate how this approach may be fully integrated with standard applications. Ideally, the scanning system would transparently replace the user interface of a commercial word processor. Implementing the scanning word processor as a separate application may prove a necessary compromise.

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A SOFTWARE ENVIRONMENT FOR TESTING THE USE OF POINTING DEVICES

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ABSTRACT

Making graphical user interfaces accessible requires testing the abilities of prospective users with different pointing devices. This paper describes the rationale, design, and implementation of a software system for testing pointing ability. A final section remarks on the use of the system in a current research project.

INTRODUCTION

Graphical user interfaces (GUI's), such as Microsoft Windows, IBM Presentation Manager, and the Macintosh Finder, require the use of pointing devices. Users of these interfaces need pointing devices best suited to their physical abilities. It might be desirable to make pointing easier for some users by altering the layout of the interface: enlarging and rearranging targets such as menus, buttons, and window gadgets.

Choosing the best pointing device for a user involves testing the user's pointing ability with a range of devices. Ability testing is also necessary for deciding how to modify the interface. Research into pointing has been conducted (Baecker and Buxton, 1987), and various systems have been developed to test the use of pointing devices (Woltosz, 1988). No consensus has yet emerged, however, as to what aspects of pointing are significant and what testing methods are most appropriate.

In the context of a research project to make graphical user interfaces accessible to people with disabilities, we have developed a software system to test the use of pointing devices. The program administers a set of generic pointing tasks and gathers data on performance. It is possible to test a person with a variety of pointing devices and compare results to choose the best one. The data are also designed to predict how the user will perform when working with actual application programs, and to suggest an optimal interface layout, by showing what locations, target sizes, and directions of movement are easiest for the user. The authors feel this system to be a step towards consistent pointing evaluation for both research and clinical assessment.

DESIGN REQUIREMENTS

Several basic requirements guided the design of the test system:

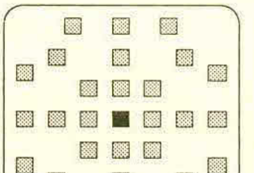
- The research team felt that testing should be precise, with each test focusing on a different aspect of pointing skill. Data collected should be complete enough for assessment but not overwhelming.
- The test system should be easy to operate. Data should be stored in a non-binary, easily readable format.
- The system should be compatible with a wide range of pointing devices.
- Since the system tests pointing skill for operating GUI's, it should perform and "feel" like an actual GUI.
- Finally, the team felt that the system should be modifiable and expandable for use in future projects.

THE TEST SYSTEM

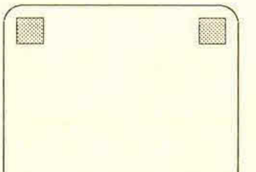
Tests

The system tests four aspects of pointing ability: pointing range, target size, target resolution, and dragging (moving the pointer while holding down the selection button). A test consists of a number of square targets on the screen which the user must point to and select. The size and position of the targets are variable. Three selection methods are possible: simply moving over the target, moving over the target and pressing a selection button, or moving over the target and pausing for a given length of time.

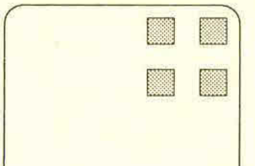
Each type of test uses a different arrangement of targets. To determine whether a user can point to all areas of the screen, the pointing range test fills the screen with twenty-nine targets in a pinwheel layout. By displaying targets at all four corners of the screen and varying their sizes, the size test establishes the smallest target the user can point to. The resolution test displays a group of four targets and varies their spacing. The dragging test displays targets at opposing corners and sides of the screen and requires the user to point to one target, press and hold the selection button, then move to the other target and release the button.



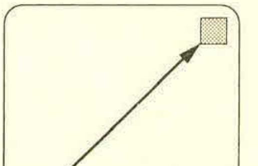
Range Test Layout



Size Test Layout



Resolution Test Layout



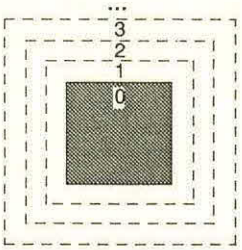
Dragging Test Layout

Data

During a test, the system collects data on timing and accuracy. For each target, the system records first the time taken to acquire (move over) it, and then the total time taken to select it. By comparing acquisition and selection times, a researcher can determine whether a user's slow performance is due to poor pointing ability or to an inappropriate selection method.

A target is surrounded by concentric ranges of error. Range 0 is the target itself; all other ranges are of a given size and are numbered outward from the target. If the range size is a tenth of an inch, for example, range 1 includes all locations within a tenth of an inch of the target edge, range 2 all those between one and two tenths, and so on. Since the error ranges are limited in number, the outermost range includes all locations outside the other ranges.

TRIAL SYSTEM



Target Error Ranges

Path Error Ranges

Whenever the user attempts to select a target by pausing or pressing the selection button, the system records in which range the pointer's location falls. Similarly, when the user is dragging between targets, the system tracks the movement of the pointer within error ranges ranked on both sides of the straight path between the targets. At the end of a test, then, for each target there is a distribution of hits and misses across the error ranges, and for each path there is a similar distribution of movement samples.

By locating data points in ranges rather than recording them individually, the system limits the quantity of data collected while preserving its utility. Researchers can choose the level of detail they want by adjusting the size of the error ranges.

Operation

For ease of use, the system is operated through menus. When running tests, researchers have several options which they specify by filling in dialog forms. These options include the number and size of error ranges, the number of test iterations, and whether to randomize the sequence of targets. The system can 'remember' option settings from session to session.

After a test, the system stores performance data in a text file. For readability, all data, including numeric values, are stored as text, and groups of data are labelled. Values are separated with commas to conform to the CSV format supported by many spreadsheets and databases.

In addition to storing detailed data, the system summarizes the user's performance in a graphical display. Histograms show average timing and accuracy.

Implementation

The system was developed in the Actor object-oriented programming environment, which runs under Microsoft Windows. Using an object-oriented language, it was possible to implement a highly modular, expandable design.

Using an actual GUI as a software environment helped meet other design requirements. Windows' built-in support for menus, dialog boxes, and graphics simplified the development of an easy-to-use, graphically intensive program. Most pointing devices work with Windows, and the team was able to write drivers for unsupported devices. Finally, Windows has the desired "feel" and operational characteristics.

METHODS

In the context of our project, the test system was used to determine the effect of pointing device modifications and interface characteristics on a user's performance. Through experimentation with different devices and device modifications, the assessor was guided by time data and error distribution to arrive at an optimal device configuration. Having optimized the user's performance with a particular pointing device, the assessor was able to examine more detailed test results and recommend changes in interface layout.

Size tests initially established the smallest target size with an acceptably low number of errors (a target size of 2-3 tenths of an inch was desirable). Resolution and range tests were then administered with this target size. Testing both large and minimal spacing determined the resolution with the fastest execution time and fewest errors. Surprisingly, certain clients were found to achieve higher speed and greater accuracy when targets were very close together than when spacing was increased. The relative ease of horizontal, vertical, and diagonal movement were also noted. To determine whether working in different areas of the user's range of movement would produce different results, the resolution trial was executed in various quadrants of the screen. The range test probed the boundaries of the user's controllable range and established an optimal range.

All three tests were repeated to assess the different effects of pressing a button or pausing to select a target. The dragging trial was used to determine whether the user could hold down the selection switch while moving between targets at various distances, and whether holding the switch affected the user's targeting ability. Once optimal scores were attained with various pointing devices, the scores achieved with each of the devices could be compared.

CONCLUSION

The test system described above appears an accurate and effective tool. Its developers feel that the principles used in its design may prove applicable to the eventual development of a standard environment for the testing of pointing ability.

ACKNOWLEDGEMENTS

We thank the University Research Incentive Fund of the Ontario Ministry of Colleges and Universities for their support. We also thank IBM Corporation for providing equipment and expertise.

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MODIFICATION OF DIRECT MANIPULATION POINTING DEVICES

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ABSTRACT

Successful control of a direct manipulation computer interface requires the use of a pointing device. For people with physical disabilities, these devices may be difficult or impossible to use. This paper describes the iterative modifications of several pointing devices in order to optimize control of a direct manipulation computer interface. The relative accessibility of various pointing devices is also discussed.

INTRODUCTION

This paper reports on the preliminary observations of a two-year project exploring the use of direct manipulation interfaces (DMIs) by individuals with physical disabilities. While DMIs were introduced to make computers accessible to a larger range of users they have created a barrier for many users.

Specific questions addressed include: can users access existing direct manipulation interfaces; what modifications to both the direct manipulation software environment and to the pointing device are necessary to optimize access; and, on a case-by-case basis, which pointing device affords the most effective performance? Although application of DMIs with computer users who use scanning has been explored, this paper discusses those users who are unable to use an unmodified standard keyboard but who have sufficient pointing skills to enter text through some direct means. Modifications to actual pointing devices, not the software interface, are addressed.

METHOD

Optimal performance was established for each user with several pointing devices. An iterative approach was used in establishing this performance: a modification was made, its effect tested, and further modifications/evaluations were made until optimal performance was reached.

Modifications included: alterations to the casing of the pointing device (e.g., adding protuberances or finger hooks), covering up and enhancing selection buttons; replacing the selection button with external switches; mounting and repositioning the pointing device; using splints and other materials to eliminate the need to hold or assist in holding the pointing device or components; modifying the positioning of the user; stabilizing the user; and adapting the software driver. Performance across pointing devices was compared after optimal performance was reached.

Optimal performance was defined as obtaining the following goals without undue physical or cognitive load:

- accurately selecting a target of a size as close to 0.2 inches as possible (size of a standard character)
- accurately selecting targets with a resolution as close to the spacing of standard characters as possible
- attaining consistant performance across the largest range (optimally the entire screen)
- making the fewest miss-hits or misselections
- achieving the fastest time

Performance was tested using application-independent trial software developed specifically to record time, misselections and targeting path. The trial software allowed adjustment of target size, resolution, dwell time and location of targets on the screen. Standard application programs were also used to evaluate functional use.

The physical subtasks of direct manipulation were defined as:

1. Moving the pointer to the target, which includes:
   a) holding or making controlled contact with the pointing device
   b) moving and stopping the pointer at the desired location.
2. Selecting the desired target, which involves:
   a) maintaining the pointer on the target while activating a button or switch.
   b) activating the button or switch at the appropriate time.
3. Dragging, which involves the previous subtasks as well as:
   a) maintaining hold on the button or switch while moving the pointer to a new location.
   b) releasing the button or switch at the appropriate time while maintaining the pointer on the second target.
4. Moving between use of the keyboard or keyboard emulator and the pointing device (Brownlow et al., 1989).

Commercial pointing devices included: the Microsoft Mouse™; Mouse-trak™ trackball; Easyl™ touch-sensitive graphics table; Summasketch™ stylus-operated graphics tablet; FreeWheel™ infrared headpointe; HeadMaster™ ultrasonic pointer; and Voice Navigator™ voice input module. Experimental devices included a proportional joystick, a long-range optical pointer (LROP), an array of four directional switches, and a voice switch. Keyboard arrow keys were also used.

Modifications to the mouse or selection button that were made for all pointing devices included: replacing the button with an external switch suited to the user's available movements; replacing a button click with dwell time (if the pointer dwells on a specific target for more than a predetermined time it is considered a selection); and latching the button or external switch (one hit depresses the button and the next releases it.)

OBSERVATIONS

Although the mouse is the pointing device most commonly used for direct manipulation interfaces, it proved to be the least accessible to our group of users. The mouse cannot be controlled by an alternate body part and must remain flat on a working surface.

Unexpected barriers caused by the design of various pointing devices were frequently encountered. For example, dragging a stylus across a pressure sensitive graphics tablet required users to maintain pressure on the selection button *and* maintain a constant pressure on the tablet with the stylus. Lifting the stylus, even while holding the button down, interrupted the operation.

Frequently, users had greatest success when pointing devices were combined or when the same user employed distinct pointing devices for different applications. It was found crucial to consider and integrate the user interface as a whole (pointing device and keyboard or keyboard replacement) when using word proccessing or any application involving text entry as well as pointing.

CASE EXAMPLES

The following case examples illustrate some of the ways that this particular group of users were able to control a direct manipulation interface.

Example 1
Y.M. has a high spinal cord injury. She uses head and neck movements to control her environment since she has very little usable movement in her upper extremities. She accesses a computer through a keyboard emulator (the LightTalker™) which accepts input from an infrared pointer. During the trials Y.M. used a trackball and LROP most successfully.

The trackball was mounted so that she could move the ball with her chin. The trackball was rotated sideways so that the handrest of the trackball would not block Y.M.'s view of the screen and so that both the latching and nonlatching mousebuttons could be easily reached. Appropriate adjustments were made to the software driver. The advantage of the trackball was that Y.M. could independently drive up to the computer and begin to use the pointing device.

Y.M. used two optical pointers in combination. The LightTalker pointer accessed the keyboard emulator, which had its own visual display and was placed directly below the main screen. The LROP accessed the main screen. Movement from text entry to pointing was very quick through redirection of head movement. Y.M. used either dwell time or a pneumatic switch to enter a mouse click and a latching pneumatic switch for dragging.

Example 2
R.K. has peripheral nerve damage making it difficult to use finger and hand movements to control an interface. Repeated use of any one movement could cause fatigue and pain. An acceptable solution was reached by combining voice input with either a trackball or a headpointer (the LROP or HeadMaster). R.K.'s primary purpose for using a computer was to write music.

Music notation programs with DMIs usually allow control of most functions and selections through either the keyboard or a pointing device. As a result R.K. was able to use the pointing devices and voice interchangeably during a session, thereby reducing fatigue and avoiding overuse of one movement. Menu items and dialog windows were most easily controlled through the voice input module. Selecting items to cut or copy, and choosing insertion points was done with the pointing device. When using the headpointer a neckrest was used to relieve neck strain and provide support for neck movement.

Example 3
A.A. has cerebral palsy with limited control of one upper extremity and head movement. A.A. is nonspeaking, communicating primarily through a letter board or portable computer. She accesses a keyboard using an isolated finger on her right hand while stabilizing her right arm with her left forearm. A.A. used the Easyl touch tablet and trackball most successfully and had limited success with the LROP.

In using the headpointer A.A. had difficulty in maintaining the pointer on the target while attempting to activate a switch with her hand or to vocalize to make the selection with a sound switch. Dwell time caused an unacceptable number of misselections. One solution was to provide A.A. with one switch to activate the headpointer. Her hand would rest on this until the target was reached, at which point she would release this switch to activate a second, select switch. The position of the pointer was frozen when she released the first switch.

In using both a graphics program and a text editing program A.A. had greatest success in combining a graphics tablet with the arrow keys and using a sound switch as a mouse button. A.A. used a finger splint with a teflon ballpoint tip to control the pressure sensitive graphics tablet since she could not hold a stylus. A rubber ring was fastened around the tip to avoid slipping off keys with the sharp teflon tip when addressing the keyboard.

The graphics tablet was used for large movements of the pointer while the arrow keys were used for fine movements or fine adjustments. Difficulty arose in positioning both the keyboard and the graphics tablet within her range. For graphics programs a graphics tablet with a set of arrow keys on the tablet would be ideal. Although nonspeaking, A.A.vocalized quickly and reliably with little overflow to her right arm. The sound switch was therefore her most successful selection button.

CONCLUSION

All of the users who participated in this project were able to access a DMI using some pointing device with relatively superficial modifications. Whether a DMI is an improvement over a command-based interface for these users remains to be determined. In order to effectively compare the two types of interfaces a similar optimization process must occur with the command-based interface.

To accomodate all but the most physically adept users, physical demands should not be increased in an attempt to decrease cognitive demands when designing user interfaces. The type of pointing device required and the pointing conventions used (e.g., dragging) should be very flexible. Designers need to pay more attention to the integration of the text entry device and the pointing device for all users.

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DON'T MANIPULATE, DELEGATE!

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ABSTRACT

Direct manipulation computer environments require the use of a pointing device, which some people find difficult or impossible. Transparent emulation of the pointing device is inadequate. A better approach might be to allow users to delegate manipulation tasks to an intelligent assistant within the computer environment. Current systems adumbrate this ideal.

INTRODUCTION

The technique of direct manipulation is a fairly recent development in human-computer interaction. A direct manipulation computer interface displays the nature and disposition of data in a rich, usually graphical, representation. Instead of manipulating the data by issuing commands to the computer, or talking about the data, the user rearranges and alters the screen representation, thereby acting on the data. Pointing devices are currently the most effective means of translating user actions into manipulation of the screen display.

While for most users direct manipulation is a fluid and intuitive interaction style, there is a group of users for which it is difficult or impossible. These users either cannot operate a pointing device or do so with great difficulty. A traditional, "transparent," alternate access method would attempt to emulate the pointing device: the user would move the screen cursor by pressing or scanning through a set of directional keys. We might also suggest that direct manipulation is simply inappropriate for some users, and that they should use a command-based interface instead. The first method is highly inefficient, however, and the second avoids the issue. (Cf. Brownlow et al., 1989.)

We should be able to devise satisfactory alternatives or enhancements to direct manipulation. Our solutions must measure up to the ideals of direct manipulation: quick and intuitive access to data, and the resulting sense of control. We might follow current trends in human-computer interaction research and allow the user to delegate tasks.

HOW TO DELEGATE

Playing the Boss

In the real world, people who are either unable or unwilling to perform tasks for themselves delegate them to others. It would seem reasonable to extend this principle into the world of the computer. If the direct manipulation of data representations is too difficult, why not create a staff of electronic assistants to do the manipulation? We should be able to give the user a more managerial role in computing.

Many computer tasks are processes involving existing data. During file operations and page layout, for example, the user manipulates files and text which are already present in the computer. In a direct manipulation file system, the user moves and copies existing files by dragging their icons from one location to another on the electronic desktop. To delete or print a file, the user drags its icon to the wastebasket or printer icon. A user who cannot point needs another method. An initial approach might be to provide a scanning system which allows the user to select file icons and their destinations. Such a system might be highly functional, but it would lack much of the psychological power of the original. In the original system, users can feel they are actually handling their files. Users of the scanning system have no such feeling of control, since they must work through a slow and awkward technique of scanning and selection.

To give the user more of a sense of authority, we can recast the scanning system in a managerial metaphor. We can relabel the desktop items as staff members of an electronic office. File icons become low-level workers, file folders become supervisors, and instrument icons such as the wastebasket and printer become staff specialists. The user issues orders to the electronic staff. Printing a file, for example, involves arranging a meeting between the lowly "worker" and the "print specialist." Now, the scanning user is delegating tasks which other users have to perform themselves.

There are two major objections to the managerial solution. We have simply taken an existing technique—scanning—and tried to present it in a different and more empowering way. Yet the scanning user is still at a disadvantage; scanning is still slower than direct manipulation. Furthermore, delegation only works for fairly simple tasks which involve existing data. The user cannot delegate data entry, and the interface cannot anticipate every complex and varied editing or processing task the user will want to perform. We need to extend the concept of delegation to be of more general utility, and to give users more power than they had before.

An administrative assistant

A better approach might follow the lead of direct manipulation in giving the user complete control over data, while also providing some degree of assistance. Alternative manipulation techniques may be devised which allow users to make the best of their abilities in handling data. For example, a word processor for scanning users might eliminate the pointing metaphor altogether, and scan through the text itself instead of through an array of direction keys.

In addition to giving the user direct access to data, an ideal system would incorporate a kind of administrative assistant. This assistant would look over the user's shoulder, as it were, and step in when needed. It would have complete access to all aspects of the computer environment, and some understanding of the task domain.

By observing the user's actions, and accepting correction from the user, the assistant would gradually build up knowledge of a range of tasks. The user could then delegate common, repetitive actions to the assistant instead of having to work through them.

Thus, in word processing, the user might want the assistant to perform tasks such as transposing chunks of text, creating footnotes, and so on. Yet there would be no barrier between the user and the data; at any time the user could choose to perform an action by manipulation. Such a system would make the most of the abilities of all users, while at the same time giving them added power by putting an intelligent assistant at their command.

CURRENT IMPLEMENTATIONS

Various research prototypes and commercial products implement some of the principles outlined in the previous section. While none of these implementations provides all aspects of the environment described above, they demonstrate the feasibility of the individual techniques involved.

Alternative manipulation

A current project at our centre is exploring the direct manipulation of text through scanning. Instead of requiring the user to scan through movement and selection commands to manipulate the text, our protoype system treats the text itself as a selection set which the user can scan through a block at a time. The principle of manipulating data by directly scanning through it may prove generally applicable.

Automation

The macros or script languages included in many application programs are very powerful, but they only work within the associated program. Hewlett-Packard's NewWave™ environment integrates macro capability into the operating system, extending the idea of a standard, system-wide batch facility. NewWave's "agent" scripts have complete control over all applications in the system (as long as they conform to the NewWave standard). An agent can automate an entire session, running applications, editing data, and transferring information. (Cobb and Weiner, 1988.)

Programming by demonstration

While most macro or script facilities can "learn" by recording user actions, making full use them requires mastering a script language and writing programs. Current HCI work is applying machine learning techniques to task automation. In a system developed at the University of Calgary, an "eager apprentice" observes the user's actions and generalizes them, learning by induction to perform tasks the user has demonstrated (Maulsby and Witten, 1989).

Intelligent environments

Other HCI work seeks to add general intelligence to the computer environment. Researchers at the University of Colorado have developed a "design environment" which guides the user through various design tasks, suggesting actions to perform and correcting errors (Fischer and Lemke, 1988).

CONCLUSION

In attempting to make direct manipulation computer interfaces accessible to people who cannot use pointing devices, it is insufficient simply to relabel old solutions or to provide awkward emulations of standard devices. We must add capabilities to the system which give more, not less, power to the user. Providing an intelligent assistant seems an effective solution. While no current system fully implements this idea, existing products and prototypes demonstrate that the necessary techniques are feasible.

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ENERGY COSTS OF WALKING AND STANDING USING FUNCTIONAL ELECTRICAL STIMULATION

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ABSTRACT

Energy data were collected on two paraplegic and one hemiplegic individuals utilizing Functional Electrical Stimulation (FES) during walking and standing. For comparison, control data were collected on two able bodied subjects for the same activities. Paraplegic and hemiplegic individuals using FES during walking used 28.8 and 18 ml O_2/kg/min respectively. The able bodied control subject used 8.64 ml O_2/kg/min during walking at the same speed of .5 m/sec. During standing with FES, paraplegic subjects used 12.6 ml O_2/kg/min as compared to normals who use less than 3.6 ml O_2/kg/min. This level of energy consumption during walking is higher than most paraplegic subjects can tolerate for prolonged periods of time.

INTRODUCTION

Paraplegic and hemiplegic individuals walk with the aid of FES (1)(2). Of primary concern is the amount of energy needed to successfully use the FES system for ambulation. Energy efficiency is an important issue concerning the effectiveness of paraplegic and hemiplegic ambulation using FES. Although energy costs are quite high we are investigating some methods to aid in increasing the overall energy efficiency of FES in hopes of enabling paraplegic and hemiplegic individuals to use the system functionally over prolonged periods of time. Our task is to determine how much energy is required by the body when FES is used to perform functional tasks, such as walking and standing, and then compare these results with energy requirements of a normal undertaking the same or similar tasks. Due to inherent inefficiency of electrical stimulation, including reverse muscle fiber recruitment and inadequate control of stimulation using preprogrammed patterns, we are striving to reduce energy consumption during various tasks to below 50% of the individuals maximal aerobic capacity.

METHODS

Collection of energy expenditure data was done on two paraplegics, one hemiplegic and two normals during resting, standing with the aid of FES, and walking with the aid of FES. Standing and walking exercise trials were also done while subjects were lying on a mat in order to ascertain the amount of energy expended by the upper body while holding onto a standard rolling walker for balance. Walking trials were done over the course of 1000 feet and speeds varied from .4 m/sec to .65 m/sec. A Sensormedics MMC Horizon System, Model MMCH, was used to analyze the energy expended. A reading was collected approximately every 15 seconds.

RESULTS

Initial results indicated that energy required for FES ambulation and standing in paraplegics was significantly higher than that required by an able-bodied individual (Table 1). The energy expended by a paraplegic using FES to ambulate was an average of 28.8 ml O_2/kg/min compared to approximately 8.1 ml O_2/kg/min for normal ambulation, at an average speed of .5 m/sec. The hemiplegic individual used 18 ml O_2/kg/min during walking. During standing, paraplegics used 12.6 ml O_2/kg/min and normals used less than 3.8 ml O_2/kg/min. All the subjects and controls used less than 4.0 ml O_2/kg/min at rest. When lying supine on a mat during walking exercise trials, paraplegics reduced their energy consumption to 20.2 ml O_2/kg/min and the hemiplegic energy consumption was reduced to 8.3 ml O_2/kg/min. During supine standing exercise trials the energy consumed in paraplegics was reduced to 10.8 ml O_2/kg/min.

DISCUSSION

When the muscles are stimulated to a fully contracted state, the amount of energy required to accommodate this type of intense contraction was 3.5 times higher in paraplegics and twice as high for the hemiplegic subject during walking as compared to normal. Reducing the amount of stimulation showed a trend towards decreasing the energy requirement. With preprogrammed stimulation there was the necessity to overstimulate the muscle to ensure that a function could be carried out over longer periods of time, so that even after fatigue was encountered the muscles were still above acceptable strength levels for safety and function. Although the muscular endurance of the paraplegics improved with stimulation, energy cost was still above 50% of their maximal aerobic capacity during walking (3). Cardiovascular endurance is not a major limitation in distance walking in conditioned paraplegics. The limiting factor is usually fatigue of the upper extremities which are required to work harder when hip instability sets in with muscle fatigue. There was a 8.6 ml O_2/kg/min reduction in energy consumption using the same stimulation pattern for walking when the subject was supine. This suggests that 30% of the energy is used by the upper extremities for balance and support during walking. The energy used during the walking trials was similar to that of a normal individual running a 7.5 minute mile with similar energy costs, respiratory rates, and exercising heart rates (4). It is very possible that this amount of energy could be tolerated for prolonged periods of time. It is as feasible as an able bodied runner running multiple miles at a 7.5 minute per mile pace. However, such a system would not be practical for everyday use.

Another interesting point was that paraplegic standing was less energy efficient than paraplegic walking. During standing the energy efficiency was at its lowest because the large muscle groups of the lower body were stimulated constantly at full strength. However, during walking the muscles were stimulated at varying degrees of strength and intermittently. Walking trials using normal control subjects showed an increase in energy efficiency with an increase in walking speed from .45 m/sec to 1.35 m/sec. The energy cost of normal walking was 8.3 ml O_2/kg/min at .45 m/sec and 14.4 ml O_2/kg/min at 1.35 m/sec. The walking speed was tripled and the energy cost was less than doubled. Increased speed introduced a greater momentum component to the walking and increased the energy efficiency. Walking at slow speeds diminished the momentum effects and thus decreased the energy efficiency.

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Table 1

Energy Costs of FES Activities

		(------------	ml O_2/kg/min	------------		------------)	(m/sec)
SUB	INJURY LEVEL	REST	WALK	STAND	EXRCISE WALK	EXRCISE STAND	WALKING SPEED
CG	T 7	4.0	29.9	13.0	20.2	10.8	.6
RL	T 9	3.4	27.7	12.6	20.2	11.2	.5
EK	hemi	3.7	18.0	1.1	8.3	NA	.5
1	Cntrl	3.2	7.6	4.0	NA	NA	.5
2	Cntrl	3.5	8.6	3.6	NA	NA	.5

Cntrl- Control Subject
hemi- Hemiplegic
T7, T9- Paraplegics

ACUTE PHYSIOLOGIC RESPONSES OF SCI SUBJECTS TO FNS KNEE EXTENSION EXERCISE

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ABSTRACT

The purpose of this study was to evaluate physiologic responses of spinal cord injured quadriplegics and paraplegics during a graded knee extension (KE) exercise test utilizing functional neuromuscular stimulation (FNS) of paralyzed quadriceps muscles. Seven quadriplegics and 7 paraplegics performed a series of 4-min stages of bilateral alternating FNS-KE exercise at loads of 0, 5, 10, and 15 kg/leg. Metabolic and cardiovascular responses were determined with open-circuit spirometry, impedance cardiography, and auscultation. Comparing rest with peak FNS-KE for both groups, the FNS-KE exercise elicited significant ($p<.05$) increases in oxygen uptake (130%, 2.3 METS), pulmonary ventilation (120%), respiratory exchange ratio (37%), arteriovenous O_2 difference (57%), cardiac output (32%), stroke volume (41%), mean arterial pressure (18%), and rate-pressure product (23%). Heart rate increased by 11% from the 5-15-kg/leg stages. Physiologic responses of quadriplegics and paraplegics were very similar, except for relative hypotension and reduced peripheral vascular resistance in quadriplegics. Graded FNS-KE exercise (to 15 kg/leg) induces small but appropriate increases in aerobic metabolism and cardiovascular responses that appear to be easily tolerated by paraplegics and quadriplegics.

INTRODUCTION

Knee extension (KE) exercise via functional neuromuscular stimulation (FNS) is used for strength and endurance training of the paralyzed quadriceps muscles in spinal cord injured (SCI) individuals (1). However, the cardiovascular responses to this exercise are not well understood (2), and such data are necessary for evaluation of its potential benefits/risks for SCI subjects. Therefore, the objectives of the current study were to document physiologic responses to FNS-KE exercise in SCI individuals, to compare the physiologic responses of quadriplegics (quads) and paraplegics (paras), and to evaluate the safety/risks of FNS-KE exercise across the range of loads typically used during FNS-KE exercise testing and training.

METHODS

Subjects

Fourteen SCI men volunteered to participate in this study. Their mean age was 32 yr, they averaged 7 yr since injury, and their functional SCI levels ranged from C6 to C7 for the seven quads and from T5 to T11 for the seven paras. Five of the quads had neurologically incomplete SCIs.

Procedures

Specially designed and constructed FNS-KE chair and stimulator systems were used to electrically induce contractions of the paralyzed quadriceps muscles (3). Subjects performed a continuous progressive FNS-KE exercise test during which steady-state physiologic responses were determined. After 5 min of rest, subjects performed 4 min of bilateral alternating FNS-KE exercise at a rate of approximately six contractions/leg/min. Loads began with 0 kg/leg and progressed by 5 kg/leg-increments every 4 min to a maximum of 15 kg/leg. Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), and pulmonary ventilation ($\dot{V}_E$) were determined with computerized open-circuit spirometry. Central hemodynamic responses (stroke volume, SV; heart rate, HR; cardiac output, $\dot{Q}$) were assessed with impedance cardiography and ECG. Systolic (SBP, mmHg) and diastolic (DBP, mmHg) arterial blood pressures were determined by auscultation. Rate-pressure product (RPP), mean arterial blood pressure (MAP), arteriovenous O_2 difference (a-$\bar{v}O_2$), and total peripheral vascular resistance (TPR) were calculated. Physiologic data were statistically analyzed with two-way split-plot analysis of variance (ANOVA), Tukey tests, one-way repeated measures ANOVAs, and independent t-tests (alpha=.05).

RESULTS

All but one para subject completed the graded FNS-KE exercise test to the 15-kg/leg stage. Most physiologic responses of quad and para groups were similar, and were, therefore, averaged together (see Table 1). When comparing rest with the peak (15-kg/leg) stage for both groups combined, FNS-KE exercise elicited significant ($p<.05$) increases in $\dot{V}O_2$ by 130%, $\dot{V}_E$ by 120%, RER by 37%, a-$\bar{v}O_2$ by 57%, $\dot{Q}$ by 32%, SV by 41%, RPP by 23%, and MAP by 18%; TPR decreased by 19%. HR increased significantly only from the 5- to the 15-kg/leg stages. Responses for MAP, TPR, and RPP for quads were significantly lower than paras at each exercise stage, as shown in Table 1.

DISCUSSION

Previous physiologic studies of FES-KE exercise (2,4,5,6) have reported doubling of oxygen uptake ($\dot{V}O_2$) and ventilation ($\dot{V}_E$), little or no change in heart rate (HR), and marked increases in arterial pressure, especially in quads. In the present study, exercise $\dot{V}O_2$ was approximately double the resting level in quads and paras. The $\dot{V}O_2$peak during FNS-KE of 0.53 L/min is lower than the $\dot{V}O_2$peak of approximately 1 L/min achieved by many SCI subjects during FNS leg cycle ergometry (7). The major differences between these exercise modes are the greater muscle mass, higher contraction frequency, and lower external resistive loads during FNS leg cycling compared with FNS-KE. These characteristics render FNS leg cycling more useful for stimulating aerobic metabolism, while FNS-KE exercise presumably relies more heavily upon anaerobic metabolism and neuromuscular factors related to higher force production of shorter duration. Due to the low levels of aerobic metabolism, central circulation, and cardiac volume- and pressure-loading elicited by FNS-KE exercise in this study, we would predict primarily local adaptations in muscles related to increased muscular hypertrophy and strength. Anaerobic metabolism would also be improved since FNS primarily recruits fast-twitch muscle fibers. Previous training studies have already documented FNS-KE training induced increases in thigh girth and muscular strength and endurance (1,8).

Pulmonary ventilation appeared to be well regulated (linear) with respect to $\dot{V}O_2$ and load during graded FNS-KE exercise. The linear increase in RER above unity at loads exceeding 5 kg/leg strongly suggests heavy CO_2 production from anaerobiosis, with perhaps the metabolic acidosis driving ventilation via humoral mechanisms (9).

The 136% increase in $\dot{V}O_2$ during FNS-KE exercise was achieved through 32 and 57% increases in $\dot{Q}$ and a-$\bar{v}O_2$, respectively. This indicates that the increase in systemic aerobic metabolism was accomplished both by increases in blood and O_2 delivery through the central circulation and by increases in the rate of O_2 extraction in exercising muscles . Peripheral extraction of O_2 appears to be the predominant of the two factors. This suggests that small increments in $\dot{V}O_2$ (2.3 METS) during FNS-KE exercise require minimal support from the central cardiovascular system and/or that little or no activation of the sympathetic nervous system is necessary to support this low level of aerobic metabolism.

TABLE 1. Physiologic Responses of SCI Subjects During FNS Knee Extension Exercise.

	Rest	0 kg/leg	5 kg/leg	10 kg/leg	15 kg/leg
ALL SCI SUBJECTS					
$\dot{V}O_2$ (L/min)	0.23 ± 0.04	0.34 ± 0.07	0.40 ± 0.07	0.46 ± 0.08	0.53 ± 0.09
$a\text{-}\bar{v}O_2$ (ml/L)	54 ± 15	68 ± 19	77 ± 15	84 ± 16	86 ± 14
$\dot{Q}$ (L/min)	4.27 ± 0.69	4.80 ± 0.59	5.26 ± 0.49	5.58 ± 0.73	6.27 ± 0.66
SV (ml/bt)	63 ± 15	73 ± 15	80 ± 15	81 ± 17	89 ± 18
HR (bpm)	69 ± 10	67 ± 11	67 ± 11	71 ± 11	73 ± 13
$\dot{V}_E$ (L/min)	9.8 ± 1.4	13.3 ± 1.5	16.1 ± 2.4	19.1 ± 2.9	21.6 ± 3.9
RER	0.84 ± 0.04	0.94 ± 0.07	1.03 ± 0.06	1.10 ± 0.06	1.15 ± 0.09
QUADRIPLEGICS					
MAP (mmHg)	66 ± 15	71 ± 9	76 ± 11	81 ± 15	83 ± 18
TPR (mmHg/L/min)	14.7 ± 3.3	15.7 ± 1.9	14.7 ± 1.0	15.4 ± 3.7	13.9 ± 3.8
RPP (bpm·mmHg/10^3)	5.5 ± 0.9	5.9 ± 1.0	6.5 ± 0.8	7.0 ± 1.3	7.9 ± 1.7
PARAPLEGICS					
MAP (mmHg)	89 ± 9	93 ± 10	95 ± 7	101 ± 11	102 ± 16
TPR (mmHg/L/min)	22.7 ± 5.2	19.9 ± 4.1	18.0 ± 3.0	17.9 ± 3.2	16.3 ± 1.8
RPP (bpm·mmHg/10^3)	8.5 ± 0.8	8.6 ± 1.4	7.7 ± 0.9	9.4 ± 0.7	9.7 ± 1.1

Since HR increased only 6%, the modest 32% increase in $\dot{Q}$ during FNS-KE appeared to be due primarily to the 41% increase in SV. This strongly suggests that FNS-KE enhances return of venous blood to the heart through alternately elevating the lower legs, activating the skeletal muscle (quadriceps) pump, and increasing the activity of the thoracic/respiratory pump. Increased cardiac filling and preload may allow enhanced myocardial performance and SV via the Frank-Starling mechanism. Consequently, the increased SV and MAP during FNS-KE may elicit the parasympathetically-mediated baroreflex through the intact efferent vagal arc. Thus, HR is depressed at the lower (0-5 kg/leg) FNS-KE loads and cardioacceleration is only slight at the higher (10-15 kg/leg) loads. Vagal withdrawal appears to be a sufficient explanation for the small increase in HR rather than sympathetic stimulation.

Whereas a marked pressor response in quads, but not in paras, had been previously reported (4,5), a small increase of MAP in both groups was observed in this study. The MAP of both groups increased, but quads displayed MAPs in the hypo- to normotensive range that averaged 20 mmHg below those of paras. TPR of quads was also lower than that of paras at all test loads. Low MAP and TPR appear to interact to allow a relatively normal $\dot{Q}$ response to exercise in quads.

From a safety perspective, the low absolute levels of peak responses to FNS-KE observed in this study probably pose little cardiovascular threat to otherwise healthy paras or quads. Even during FNS-KE exercise at the 15-kg/leg stage, the RPP (an index of myocardial $\dot{V}O_2$ or cardiac stress) remained within the normal resting range. Overall, the cardiovascular responses observed in this study were appropriate for the low level of aerobic metabolism induced by FNS-KE and were well tolerated by healthy SCI subjects. One potential risk in quads during FNS-KE may be hypotension. Although completely without symptoms, arterial blood pressures near 70/40 mmHg were observed before the test at rest and during FNS-KE exercise in three quadriplegic subjects, two of which were neurologically incomplete. During FNS-KE exercise, their BPs generally increased toward normotensive levels. Additionally, no orthopedic complications were encountered during testing, perhaps due to the load limit of 15 kg/leg. Those administering this exercise for research or clinical purposes are cautioned to monitor BP in all quads and limit maximal FNS-KE loads.

CONCLUSIONS

The physiologic responses of these SCI subjects indicate that graded FNS-KE exercise stresses the O_2 transport systems to a very low degree. FNS-KE induces mild cardiac volume- and pressure-loads that are easily tolerated by and appear to be safe for paras and quads. Physiologic responses of quads and paras are similar, except for the relative hypotension and reduced peripheral vascular resistance in quads.

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AUTOMATED ADAPTIVE EQUALIZATION SYSTEM FOR ASYNCHRONOUS FNS-INDUCED KNEE EXTENSION EXERCISE FOR SCI SUBJECTS

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ABSTRACT

An automated system for exercising the lower extremities of spinal cord injured patients using functional neuromuscular stimulation (FNS) has been developed. Operation of the system causes knee extension and flexion in the vertical plane during automated adaptively controlled ramped increases and decreases of current intensities within a predetermined range of motion from 0-70^{o}. Lower limb exercise is accomplished as the limbs push against lever arms equipped with adjustable load (weights). The system uses the adaptive equalization method to control FNS of the quadriceps muscles to induce sequential concentric and eccentric contractions of the muscles in both limbs. FNS parameters and control signals necessary to track the predetermined range of motion are acquired and adjusted dynamically for proper and safe operation of the system. Tests indicated that the system is able to operate within predetermined range of motion satisfactorily as designed. Simulated safety problems such as hyper-extension of the knee joint, open circuitry, muscle spasms and low power were successfully detected and the system followed appropriate safety procedures.

INTRODUCTION

Various devices have been developed for FNS training of paralyzed lower extremity musculature of spinal cord injured (SCI) individuals via linear control methods [1-4]. However, repetitive FNS of paralyzed muscles causes non-linear increases in threshold stimulation current [5,6] and stimulated paralyzed muscles have nonlinear gain and possibly time-varying characteristics [5-7]. The performance of a system for efficient and smooth control of paralyzed limb movement requires that the system be able to adapt to nonlinear characteristics of the electrically stimulated paralyzed muscles. This paper describes an automated adaptive equalization system (AAES) for asynchronous FNS assisted movement of lower limbs of SCI individuals.

SYSTEM DESCRIPTION

Figure 1 illustrates the functional block diagram of the various subsystems which include: *(A) Ramp and Exponential Generator (R&EG)*: This stage takes one control signal from the control logic when activated and starts increasing the output voltage. When the control is deactivated, it ramps down to zero and waits for the next control signal. The ramped output wave could be linear, exponential or the combination. *(B) Stimulator Output:* This stage takes input from the ramp and exponential generators (R&EG) and converts them into current-regulated pulse output where current varies as the input voltage. The output current is limited to 150 mA. Output pulses are 300 microseconds long at a repetition rate of 35 Hz. *(C) Asynchronous adaptive equalization (AAE)*. This stage presents the previous threshold stimulation current value to the R&EG. This value is used to account for the expected threshold value for the next contraction.

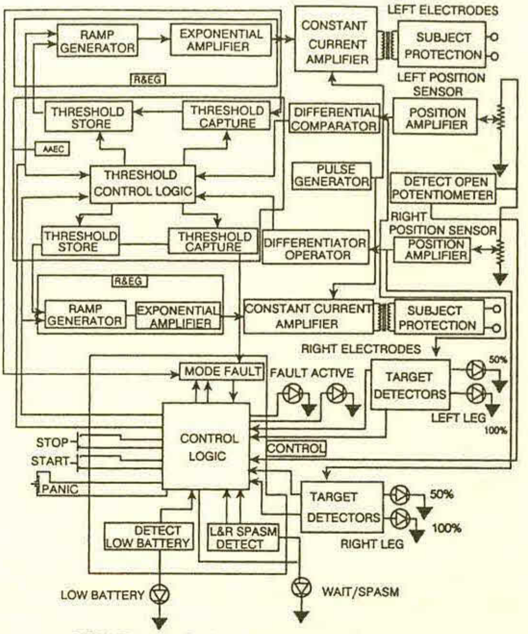

FIGURE 1. FUNCTIONAL BLOCK DIAGRAM OF AAE SYSTEM

(D) Position Sensing System: This system supplies a bias voltage to the exercise chair's electronics and receives a voltage from the potentiometer on each lever arm of the chair. The voltage is proportional to the angle between the weight arm and the vertical. It has series of comparators to monitor position voltages from the weight arms against preset voltage values. One set is preset to fire a pulse at 35 degree level of the lever arm extension, which is 50% of predetermined target angle of 70°. Another set fires at the target angle (70°). The output of each of the position sensors is taken to a differentiating circuit followed by another comparator which indicates the start of limb movement. This information is used by AAES to memorize the threshold value of contraction. *(E) Adaptive Asynchronous Equalization Controls (AAEC)*: When the system is first turned on, all variables used for FNS control such as the threshold current value, position sensor values, the 50% and 100% conditions are initialized and the fault detect circuits are cleared. When the R&EG are activated, both the R&EG and AAEC receive the same signal from the control system. This in effect cues the AAEC to release the preset voltage to the R&EG to start at the expected threshold value. When the leg starts to move, the position sensor immediately sends a signal to the AAEC to indicate the start of leg movement (threshold condition). The AAEC then captures and remembers the threshold stimulation current (voltage) value upon receiving this signal. *(F) Control System*: The control system performs the following tasks: 1) It alternates the sequence of contraction from the left to the right leg and vice versa. 2) It sends a signal to the ramp

generator to ramp down if (i) the knee extension reaches the target angle (70°) or the stimulator output reaches the maximum output, and (ii) one/both of the legs is/are fatigued. 3) It monitors the entire system, detects and shuts it down if any of the following fault conditions exist; i) low battery, ii) open sensor circuit, iii) if R&EG continues to ramp up when the control signal indicates the opposite, and iv) if spasms occur.

SYSTEM PERFORMANCE

Figure 2 illustrates the setup which comprises of an exercise chair, lever arms loaded with weights and the AAES. The quadriceps muscles contract concentrically on stimulation to lift the subject's lower limb, lever and weight against gravity. Figure 3(A) illustrates the relationship between the knee extension within 0-70° range of motion and the applied stimulation current, while Figure 3(B) illustrates the asynchronous right and left knee extension process. Four conditions represent when the muscle is fresh (i&1), after repeated contraction before muscle fatigue (ii&2), early signs of fatigue (iii&3), and during muscle fatigue (iv&4). When the muscle is fresh, it takes lower current intensities (Figure 3, 1) for the knee to extend through the range of motion (Figure 3, i) for the same amount of load. With repeated knee extensions, the threshold current (Figure 3, T) increased continuously. This phenomenon has been reported in our previous studies [5&6]. Feedback systems and adaptive techniques are used to apply the necessary stimulation parameters such as threshold stimulation current, ramp characteristics (linear, exponential or combination) to the quadriceps muscles to ensure smooth knee extension. The system was designed to permit continued knee extension if the extension is above 50% of the range of motion (Figure 3, i-iii), but to shut down if the extension is less than 50% (Figure 3, iv). Figure 3(B) illustrates asynchronous knee extension where variable delay systems were implemented to synchronize ramp-down in one leg with ramp-up in the other leg. The system has been used to train the quadriceps muscles of SCI subjects and marked information on performance reported (8).

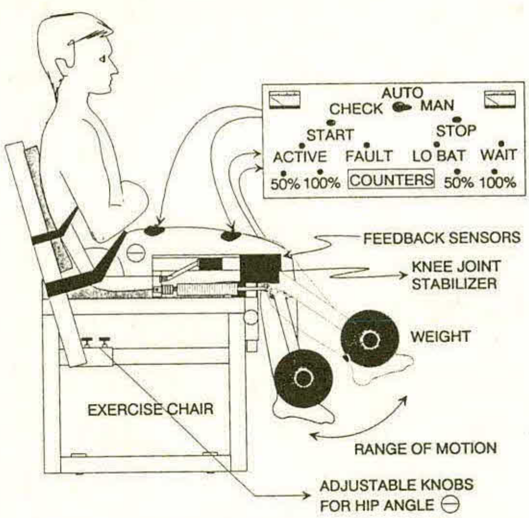

FIGURE 2. SETUP FOR ADAPTIVE EQUALIZATION FNS EXERCISE SYSTEM

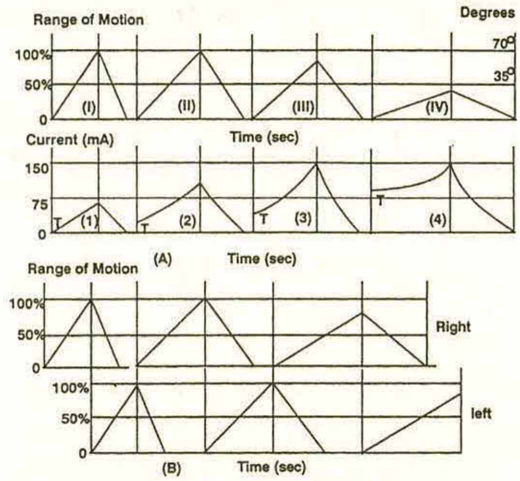

FIGURE 3. (A) RANGE OF MOTION AND CURRENT Vs TIME (B) RANGE OF MOTION Vs TIME RIGHT AND LEFT RELATIONSHIPS

CONCLUSION

The AAES has been used to train the quadriceps muscle of SCI subjects, it could also be used to plan therapy.

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MUSCLE FATIGUE CHARACTERISTICS WITH FNS-INDUCED CONTRACTIONS

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ABSTRACT

Functional neuromuscular stimulation (FNS) may be useful in restoring purposeful movements to muscles paralyzed by spinal cord injury (SCI). However, fatigue characteristics of these muscles are not well documented or understood. The purpose of this study was to monitor decrements in the performance of paralyzed quadriceps muscles during a sequence of static FNS-induced contractions. For this, surface electrode FNS (300 microsecond pulses at 35 Hz) current was linearly ramped between 0 and 150 mA (max), or to a max force output of 147 N (15 kg x 9.8 m/sec^2) as measured by a strain gauge at the ankle level. During the exercise session, contractions varied from 24-14 sec in duration, followed by 6-16 sec of rest. Generally, it was found that max force output occurred at the point of max FNS current which suggests that more motor units may be recruited and greater force output achieved if FNS current is further increased. Decrements in max force output were found with each consecutive contraction, as were increases in the threshold current. These data suggest that there was progressive fatigue of the stimulated motor unit domain. Greater max force output was elicited from FNS-trained muscles, and decrements in performance occurred at a lower rate.

INTRODUCTION

FNS-induced contractions of paralyzed muscles can potentially enable performance of skilled activities which may improve the rehabilitation outcome of SCI patients. In order to design FNS systems that are safe and effective, understanding is required of muscle contraction characteristics and patterns of fatigue. Recently, a muscle performance evaluation system was developed to monitor the relationship between FNS current and muscle force output (Ezenwa, *et al.*, 1989). This system can enable objective study of numerous variables that can affect muscle contraction characteristics. The purpose of this study was to monitor decrements in the performance of paralyzed quadriceps muscles during a sequence of static FNS-induced contractions. These decrements in performance were compared between muscles that were highly FNS-trained (Rodgers, et al., 1990) and those that were not.

METHODS

The instrumentation used for this study included an exercise chair, an isometric force sensor at the ankle level, a support around the leg to distribute the generated force over a larger surface area, a constant current stimulator with ramped output up to 150 mA, surface electrodes over motor points of the quadriceps muscle group, a signal conditioning system, chart recorder, and a computer for data acquisition (Ezenwa, 1989). A total of 20 SCI subjects were used for this study. Each subject was informed as to the purposes of the study, any known risks, and their right to terminate participation at will without penalty. Willingness and understanding was indicated by the signing of a statement of informed consent. The experimental protocol consisted of ramped FNS current from 0 to 150 mA, or to a level that induced a contraction force of 147 N. FNS current then ramped down to 0 mA. Muscles were stimulated every 30 sec for 40 contraction trials, or until the muscle fatigued to 25% of its original force output.

RESULTS

Figure 1 illustrates the relationship between FNS current and force output of highly FNS-trained quadriceps muscles of a subject who participated in our exercise training program for over a year. The subject's muscle was able to achieve the targeted force of 147 N on all 40 trials. The current required to produced this force gradually increased from 76 to 100 mA. The threshold current (for force output) gradually and progressively increased from approximately 20-40 mA. Figure 2 illustrates the relationship between FNS current and force output of a subject who is new to our exercise training

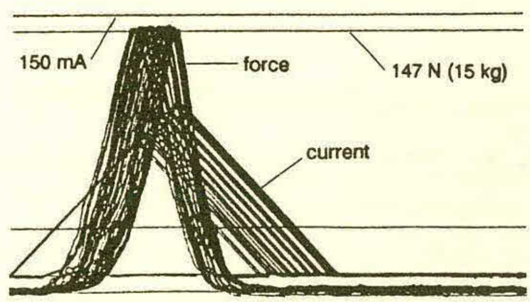

Figure 1. Relationship between stimulation current and force output of a highly FNS-trained quadriceps.

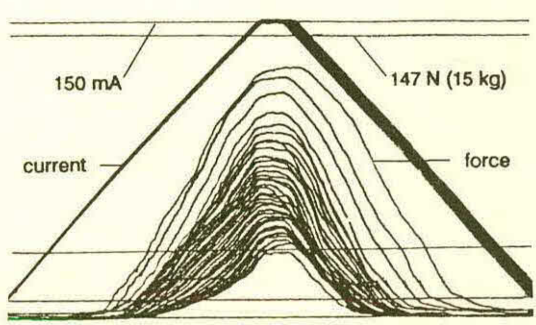

Figure 2. Relationship between stimulation current and force output of an FNS-untrained quadriceps.

program and has had only initial FNS exposure for habituation. The full 150 mA of current was required for every contraction of the muscle of this subject. With each successive contraction, the force output decreased and the threshold current increased. In all subjects, it was observed that maximal force output occurred at the point of maximal FNS current.

Figure 3 illustrates the computer-generated plot of FNS current vs muscle force output for every 5th contraction for a moderately FNS-trained subject. During the 40 contractions, there was a decrement in maximal force output, a decrease in the force generation slope and a

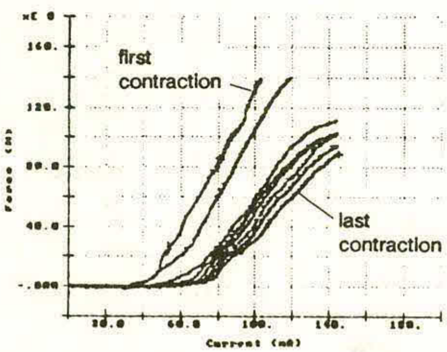

Figure 3. Computer-generated plot of FNS current (mA) vs the force generated by a quadriceps muscle for every 5th contraction.

rise in threshold current. Figure 4 illustrates the force generated per unit of FNS current (F/I = N/mA) for 13 SCI subjects. Subjects who exhibited a high F/I ratio were highly trained, subjects with a middle F/I ratio were moderately trained, whereas subjects with a low F/I ratio were relatively untrained. Data were plotted for every 5th contraction trial. The F/I ratio decreased almost linearly with each successive plotted trial for the trained subjects. However, the F/I ratio tended to markedly decrease during the first five contractions for the untrained subjects, but then decreased more linearly until fatigue. Five relatively untrained subjects fatigued prematurely and could not complete the 40 contractions.

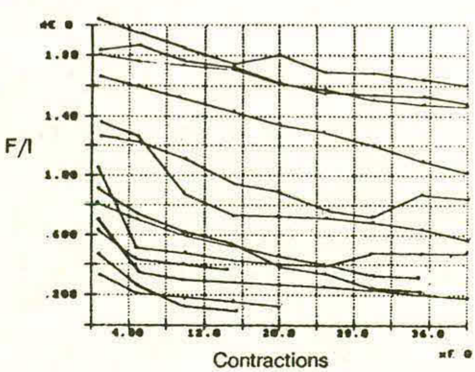

Figure 4. Force per unit FNS current (F/I) for every 5th contraction for 13 SCI subjects.

DISCUSSION

If FNS is to be used to precisely control paralyzed muscles to enhance the rehabilitation outcome of SCI patients, the changes in contraction characteristics and stimulation parameters that occur with successive contractions needs to be thoroughly understood. The present study demonstrated that there was a decrement in muscle performance with each forceful FNS-induced isometric contraction. Since maximal force output always occurred at the point of maximal FNS current, it is apparent that the maximal current used was capable of recruiting only a limited domain of motor units rather than all motor units. Thus, the progressive fatigue observed could not be compensated for by recruitment of additional motor units without increasing maximal FNS current. Therefore, it is recommended that future studies focus upon the percentage of motor units recruited for the specific FNS parameters utilized.The increase in threshold current with each successive contraction can also be accounted for by motor unit fatigue, since more current would be required to recruit additional motor units. Thus, the initial level of FNS current needs to be progressively increased as fatigue occurs to maintain proportional control of force output.

This study clearly demonstrated that chronic FNS knee extension exercise training can markedly improve performance characteristics of quadriceps muscles. Subjects who were highly trained were able to achieve higher force outputs with less decrement in performance during the 40 consecutive contractions. This is in contrast to the rapid fatigue observed in untrained muscle which occurred at quite low levels of force output.

In conclusion, additional research needs to be conducted on changes in muscle performance characteristics during the use of FNS. As the mechanisms of fatigue are better understood, FNS systems can be better designed to enhance performance.

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CARDIOVASCULAR RESPONSES TO COMBINED ARM CRANK EXERCISE AND FNS-INDUCED KNEE EXTENSION IN PARAPLEGICS

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ABSTRACT

Six paraplegic males performed arm crank exercise (ACE) alone and during simultaneous functional neuromuscular stimulation (FNS_{KE}) of leg muscles to determine the metabolic and cardiovascular effects of FNS during ACE. FNS_{KE} exercise consisted of bilateral alternating knee extensions (quadriceps only) at 6 repetitions·min^{-1} for each leg. Steady-state exercise heart rates and oxygen uptakes were not significantly different during ACE compared to ACE+FNS_{KE}, suggesting that FNS knee extension exercise does not contribute appreciably to whole body metabolism during arm exercise. Furthermore, cardiac output and stroke volume were not substantially increased by FNS knee extension at rest or during submaximal ACE. These data are in marked contract to previous studies comparing hybrid exercise (i.e. voluntary arm cranking during FNS-isometric contractions or FNS-leg cycling) with ACE, and may be explained by the fact that only a single muscle group was stimiulated in the present design. The results also support the view that FNS knee extension exercise does not ameliorate venous pooling or augment whole-body metabolism at rest or during arm exercise in paraplegics.

INTRODUCTION

In the last decade, the technique of functional neuromuscular stimulation (FNS) has been used as a rehabilitation tool in a variety of patient populations with disuse atrophy (1). Recently, Davis and colleagues (2) and Hooker et al. (3) have reported upon pilot studies whereby voluntary arm cranking was performed during simultaneous FNS-induced leg muscle contractions. In the former study (2), male paraplegics underwent submaximal arm crank ergometry (ACE) during concurrent ***FNS-induced isometric contractions*** of thigh and calf muscles. During FNS isometric leg exercise, cardiac output and stroke volume were elevated by 7%-19% during ACE+FNS compared to ACE alone. In the latter study (3), tetraplegics developed higher $\dot{V}O_2$'s and cardiac outputs during arm cranking with concurrent ***FNS-induced leg cycling*** compared either modality by itself. These investigations suggested that FNS-induced contractions of the legs increased venous return of blood to the heart and augmented stroke volume by "reactivating" the skeletal muscle pump at rest or during arm exercise in SCI subjects.

In this paper, we report our experience with arm cranking during concurrent FNS knee extension in male paraplegics. The purpose of the present investigation was to examine the cardiovascular and metabolic effects of simultaneous ***FNS-induced knee extension*** exercise during arm crank ergometry.

METHODS

Six asymptomatic SCI men (age = 25.3 ± 2.0 yr, $\dot{V}O_2$peak = 2.07 ± 0.2 l·min^{-1}) with lesion levels between T4 and T10 were recruited for the present study. The subjects had previously undergone medical examination, informed consent, 1-3 weeks of FNS habituation and assessment of physical characteristics as described by Davis et al. (1). Subjects operated an arm crank ergometer (ACE) while oxygen uptake ($\dot{V}O_2$) and expired ventilation ($\dot{V}_E$) were determined via open circuit spirometry. Submaximal heart rate (HR), cardiac output ($\dot{Q}$), and stroke volume (SV) were estimated with transthoracic impedance cardiography at rest and immediately following 6-7 min of steady-state ACE at 30 W, 60 W and 90 W. Arteriovenous oxygen extraction (a-$\bar{v}O_2$ diff) and total peripheral resistance (TPR) were calculated from $\dot{V}O_2$, $\dot{Q}$ and ausculated blood pressures.

The subjects performed two exercise tests in randomised order consisting of; a) **ACE** alone, or, b) ACE with FNS knee extensions (**ACE+FNS_{KE}**). ACE+FNS_{KE} exercise comprised arm cranking during simultaneous FNS-induced knee extensions of quadriceps muscles (4). A two channel electrical stimulator delivered biphasic pulses of 0.3 msec duration at 35 Hz through surface electrodes located over the neuromuscular motor points (4). A duty cycle of 10 s at 50% (i.e. 5 s quadriceps stimulation followed by 5 s recovery) produced an alternating pattern of limb movements at a rate of 6 contractions per minute for each leg. The stimulation pattern consisted of 2.5 s ramped increase of FNS to full knee extension (monitored by position feedback sensors mounted near the knee) followed by a 2.5 s ramped decrease of voltage output.

The physiological data were analysed via two-way ANOVA to assess differences between trials (ACE versus ACE+FNS_{KE}) and across exercise levels (Rest, 30 W, 60 W, 90 W). Differences of hemodynamic responses to FNS were considered significant at the 5% level.

RESULTS

The physical characteristics of the subjects have been previously reported by Davis et al. (2). The steady-state values for $\dot{V}O_2$, HR, SV, $\dot{Q}$, and a-$\bar{v}O_2$ diff during ACE and ACE+FNS_{KE} are listed in Table 1. There were no differences of physiologic response between ACE and ACE+FNS_{KE} at rest, 30 W , 60 W or 90 W ACE.

Table 1. Physiologic responses to arm cranking during FNS knee extension in SCI subjects (N = 6).

	REST	30 W ACE	60 W ACE	90 W ACE
$\dot{V}O_2$, $l \cdot min^{-1}$				
No FNS	0.28 ± 0.02	0.85 ± 0.08	1.28 ± 0.18	1.76 ± 0.06
FNS_{KE}	0.33 ± 0.04	0.92 ± 0.03	1.29 ± 0.04	1.77 ± 0.10
HR, $b \cdot min^{-1}$				
No FNS	66 ± 4	106 ± 9	137 ± 9	152 ± 2
FNS_{KE}	67 ± 6	101 ± 4	133 ± 7	154 ± 7
SV, ml				
No FNS	74 ± 6	83 ± 11	81 ± 12	80 ± 14
FNS_{KE}	77 ± 8	90 ± 10	89 ± 11	83 ± 7
$\dot{Q}$, $l \cdot min^{-1}$				
No FNS	4.90 ± 0.53	8.58 ± 1.06	10.64 ± 1.16	12.13 ± 1.96
FNS_{KE}	5.27 ± 0.87	9.14 ± 1.26	11.66 ± 1.56	12.88 ± 1.62
a-$\bar{v}O_2$ diff, $ml \cdot l^{-1}$				
No FNS	5.76 ± 0.46	10.37 ± 1.02	12.61 ± 1.27	15.66 ± 2.50
FNS_{KE}	6.94 ± 1.07	10.67 ± 0.97	11.95 ± 1.37'	13.84 ± 0.84

Values are mean ± SE. ACE is arm crank ergometry. FNS_{KE} is bilateral alternating FNS-induced knee extension (quadriceps only).

Estimates of gross muscular efficiency during ACE were 10.1 ± 0.9 % (30 W), 12.1 ± 0.7 % (60 W) and 15.6 ± 0.8 % (90 W), and these data were not appreciably altered under the ACE + FNS_{KE} condition. Cardiac output and left ventricular stroke volume during FNS-induced knee extension were slightly higher than at rest or during ACE, but these differences were not statistically significant.

DISCUSSION

Recently, the term "hybrid exercise" has been adopted to describe regimens of voluntary arm cranking combined with FNS-induced leg muscle contractions (1). Davis and co-workers (2) noted that $\dot{Q}$ and SV were increased by 7-19% at rest and during submaximal ACE in paraplegics undergoing pulsatile isometric contractions of thigh and calf muscles. However, such FNS-induced static leg exercise did not augment $\dot{V}O_2$ during hybrid exercise. Similarly, Figoni et al. (5) reported unchanged $\dot{V}O_2$ or HR at rest and 12.5 W ACE during upright tilting with FNS-induced static muscle contractions, despite significantly increased SV and $\dot{Q}$. In contrast, Hooker and colleagues (3) observed significantly higher $\dot{V}O_2$ and HR during ACE with FNS leg cycling compared to ACE alone. The authors also noted larger increases of $\dot{Q}$ and SV (in the range of 22-47%) during hybrid exercise utilising leg cycling than had been previously reported for regimens involving FNS isometric muscle contractions. Yet these findings may be partially explained by their use of tetraplegics as subjects, who may have had greater venous pooling and/or a more severe impairement of efferent sympathetic pathways than paraplegics.

Although a slight (non-significant) trend to increased $\dot{Q}$ and SV was evident in this study, the present data support the conclusion that FNS-induced knee extension exercise does not augment cardiovascular or metabolic responses during voluntary arm cranking. Clearly, dynamic stimulation of one muscle group (quadriceps) on each leg has only minimal effect upon reactivating the venous muscle pump. This finding is in marked contrast to FNS cycling or pulsatile isometric contractions which activate 6-8 muscle groups, thereby enhancing venous return and increasing stroke volume (2, 3, 5). Finally, lack of a significant metabolic activation ($\dot{V}O_2$, a-$\bar{v}O_2$ diff) and unchanged gross muscular efficiencies suggest that FNS_{KE} may provide no better aerobic training stimulus than arm crank exercise alone.

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PHYSIOLOGIC TRAINING EFFECTS OF FUNCTIONAL NEUROMUSCULAR STIMULATION LEG CYCLE EXERCISE IN THE SPINAL CORD INJURED

16.6

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ABSTRACT

The purpose of this study was to assess physiologic training effects of functional neuromuscular stimulation leg cycle ergometer (FNS-LCE) exercise in 12 spinal cord injured (SCI) persons who were untrained in this activity. FNS-LCE training was performed on an "ERGYS 1"TM ergometer 10-30 min/day, 2-3 days/week for 12-16 weeks (36 total training sessions). Compared with pre-training, this SCI group exhibited significantly ($p \leq 0.05$) higher post-training peak power output (+43%), oxygen uptake (+18%), and pulmonary ventilation (+24%). Although peak heart rate (+10%), cardiac output (+10%), and arteriovenous oxygen difference (+5%) increased, the differences were not statistically significant ($p > .05$). Mean arterial blood pressure (-6%) and total peripheral resistance (-15%) tended to decrease ($p > .05$). There was no change in stroke volume. It appears that much of the improved exercise performance following this initial phase of FNS-LCE training is due to peripheral adaptations that enhanced muscular strength and endurance. However, greater magnitudes of cardiopulmonary responses at the higher power outputs achieved post-FNS-LCE training could possibly improve cardiopulmonary system training capability.

INTRODUCTION

Recent studies have indicated that FNS-LCE exercise training promoted a marked improvement in peak exercise performance in SCI subjects (5,6). This improvement was indicated by significant increases in peak oxygen uptake (VO_2) and the time to fatigue and load resistance used during FNS-LCE exercise. It is currently clear that FNS training of paralyzed muscles can markedly enhance strength and endurance (5), and that the augmented exercise performances observed following FNS-LCE training may be primarily due to peripheral adaptations (7,8). However, since FNS exercise is peripherally induced, and in effect by-passes the central nervous system, it is not clear how this training will affect central hemodynamic responses. Evaluation of central hemodynamic responses, such as peak cardiac output (CO) and left ventricular stroke volume (SV), is essential to better understand how the cardiovascular system supports the higher levels of aerobic metabolism that occur with training. They also can indicate the potential of FNS-LCE training for promoting cardiovascular fitness. Therefore, the purpose of this study was to assess the peak aerobic metabolic and central hemodynamic responses in SCI subjects following an initial FNS-LCE training program.

METHODS

Seven quadriplegic (C5-C8/T1) and 5 paraplegic (T4-T8) SCI individuals (mean $\pm$ SD: age = 29.2 $\pm$ 5.4 yr, body mass = 74.7 $\pm$ 15.0 kg, time since injury = 7.0 $\pm$ 4.8 yr) participated in the study. Ten subjects had complete lower-limb motor loss. Eight subjects had participated in previous FNS-LCE exercise studies, but they did not have access to an FNS-LCE for at least 4 weeks prior to the present study. This study was approved by the University Intsitutional Review Board..

Each subject completed a discontinuous graded FNS-LCE test to fatigue for pre- and post-training assessments of peak power output (PO) and physiologic responses. FNS-LCE was conducted on an "ERGYS 1" leg cycle ergometer (Therapeutic Technologies Inc., Tampa, FL) utilizing surface electrodes over quadriceps, hamstring, and gluteal muscle groups. VO_2 and pulmonary ventilation (V_E) were determined with computerized open-circuit spirometry. Arterial blood pressures were determined via auscultation. Central hemodynamic responses of heart rate (HR), SV and CO were determined noninvasively via ECG and impedance cardiography. Arteriovenous oxygen difference (a-v O_2 diff), mean arterial pressure (MAP), and total peripheral resistance (TPR) were calculated.

FNS-LCE training was performed 10-30 min/day, 2-3 days/week for 12-16 weeks (36 total training sessions). Subjects adhered to a training protocol recommended by the ERGYS 1 manufacturer (9). Data were analyzed with one-way analysis of variance and Tukey's *post-hoc* tests (alpha = .05). Data are reported as mean $\pm$ SD.

RESULTS

Mean duration of the training program was 13.3 $\pm$ 1.7 weeks (2.7 sessions per week). Mean peak values for pre- and post-training metabolic and hemodynamic responses are listed in Table 1. Compared to pre-training levels, this SCI group exhibited significantly higher post-training peak PO, VO_2, and V_E. There were tendencies ($p > .05$) for increases in peak HR, CO, and a-vO_2 diff, as well as decreases in MAP and TPR. No difference was observed for SV.

DISCUSSION

Questions had been previously raised concerning the mechanisms by which the cardiovascular system is regulated during FNS exercise (5). Since FNS peripherally induces contractions and SCI interrupts pathways for autonomic sympathetic control (1), the typical central hemodynamic responses (e.g., HR, SV, CO) that are observed with voluntary leg exercise by able-bodied individuals may not occur to the same extent with FNS-LCE exercise by SCI individuals. In order to promote training adaptations of the cardiovascular system, marked elevation in these variables is desirable.

The present study demonstrated significant increases in PO and peak VO_2. The higher post-training peak VO_2

Table 1. Peak power output, metabolic, and hemodynamic responses pre- and post-FNS LCE exercise training. Values are mean $\pm$ SD.

	Pre-training	Post-training	% Change	P value
PO (W)	14.2 (6.0)	20.3 (7.5)*	+43%	.01
VO_2 ($l \cdot min^{-1}$)	0.83 (0.3)	0.98 (0.2)*	+18%	.01
V_E ($l \cdot min^{-1}$)	30.1 (5.2)	37.4 (9.7)*	+24%	.01
HR ($b \cdot min^{-1}$)	95.8 (16.8)	105.0 (16.3)	+10%	.06
SV ($ml \cdot b^{-1}$)	92.9 (16.6)	93.3 (17.5)	0%	.95
CO ($l \cdot min^{-1}$)	8.8 (1.9)	9.7 (2.3)	+10%	.15
a-v O_2 diff ($ml \cdot 100ml^{-1}$)	9.3 (1.7)	9.8 (2.9)	+ 5%	.47
MAP (mmHg)	88.2 (23.0)	82.6 (14.5)	- 6%	.32
TPR ($mmHg \cdot l^{-1} \cdot min^{-1}$)	10.3 (3.0)	8.8 (1.8)	-15%	.12

* posttraining level significantly different from pretraining level ($p \leq .05$)

was supported by increases in both peak a-v O_2 diff and CO. Elevated peak a-v O_2 diff suggests that the active muscles were extracting more O_2 from the blood supply. The elevated CO was accomplished by increased HR rather than SV. It is plausible that FNS-LCE activity in itself enhances SV to relatively high levels due to activation of the venous muscle pump (2,3,4,6). This effect may reduce the likelihood of observing a SV change with training. The post-training reductions in MAP and TPR suggest greater dilation of the peripheral vasculature. This would facilitate CO and the delivery of blood to the active muscles. It is interesting to note that the post-training peak V_E level closely followed the elevated peak VO_2. Thus, although precise control mechanisms for cardiopulmonary responses during FNS-LCE are presently a topic of speculation, the peripherally induced skeletal muscle contractions resulted in what might be considered appropriate central circulatory and pulmonary adjustments. However, specific components of central nervous system and/or humoral control still need to be researched.

To date, none of the FNS-LCE training studies can clearly differentiate between the degree of peripheral (i.e., muscle) vs. central (cardiopulmonary) training effects. Improvement in exercise performance can be due to either one or both mechanisms. Higher peak cardiopulmonary responses achieved post-training may have occurred because the SCI subjects had some cardiopulmonary reserve that was unused prior to training due to deficient lower-limb muscle strength and endurance that resulted in fatigue at low PO and peak VO_2 (2,6). It is also conceivable that the FNS-LCE training promoted improved cardiopulmonary function, and that greater blood (with its O_2 and fuel) availability to the muscles resulted in better exercise performance.

Nevertheless, the greater cardiopulmonary responses at the higher PO achieved post FNS-LCE training could possibly improve cardiopulmonary system training capability. Such improvements in the general wellness of the SCI population would be clinically significant since they are at an increased risk for cardiovascular and related diseases. Higher levels of cardiopulmonary fitness may also contribute to reduced stress when performing activities of daily living.

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FOUR-FUNCTION HYBRID ARM PROSTHESIS INCORPORATING AN ELECTRIC WRIST ROTATOR AND PROTOTYPE ELECTRIC PREHENSOR

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ABSTRACT

A clinically-applied hybrid arm prosthesis, developed for a high-level bilaterally involved individual with associated physical impairments, is described. The above elbow prosthesis includes a mechanical cable-actuated elbow, an electric wrist rotator, a manually-operated positive-locking flexion wrist, and a prototype electric prehensor. The component selection and rationale are discussed.

INTRODUCTION

The use of body-powered components in arm prostheses has many advantages for the person with high level bilateral amputations (1). For such persons, we have advocated fitting the dominant side with multi-function body-powered systems, in which a single control cable is used to position the elbow and wrist and to open a split hook prehensor. Our experience indicates that a potential user must be able to displace the control attachment hanger at least 2 in. (50 mm), with respect to the most proximal housing anchor or retainer, and with a pulling force in excess of 30 lb_f (133 N) for this type of prosthesis to be used effectively[1].

When either excursion or strength is physiologically limited, a hybrid prosthesis incorporating mechanical and electric-powered components may be indicated. One such hybrid design, developed for a person with high-level bilateral amputations and residual strength and movement limitations, is described.

BACKGROUND

Following an electrical accident, the client had amputations performed at the interscapulothoracic (IST) level on the left side and at the above elbow (AE) level on the right side. The right residual limb also has restricted range of motion at the shoulder, and forward flexion of the arm together with scapular abduction provide only two inches of inter-socket displacement. With an excursion amplifier, this person is unable to exert enough force to fully open a split hook prehensor against two rubber bands. Consequently, prehension using a voluntary-opening split hook is inadequate for most activities, such as handling utensils for eating. Therefore, an electric-powered prehensor is indicated.

The trauma also resulted in neurological damage affecting the coordination of lower leg muscles for balance and walking. A wheelchair is typically used for mobility, but restricts the use of trunk motion to compensate for the arm prosthesis.

The left IST amputation, the impairment of the lower limbs, and the restriction of trunk mobility (when using the wheelchair) place great emphasis on the AE prosthesis for its manipulative function. To provide the maximum versatility in the placement and orientation of the prosthetic prehensor, flexion and rotation at the wrist is required, as well as elbow flexion and extension.

After the client received his first preparatory prosthesis, three major revisions were made to the prosthesis over a period of twenty-one months. The most recent (August 1989), and most refined configuration, is presented.

COMPONENT SELECTION

Elbow

It is our experience that cable control of a mechanical elbow through body movement generally provides greater finesse in positioning of the forearm and control over the dynamics of the movement than can be achieved with switch or myoelectric control of an electric elbow. Therefore, the available cable excursion was relegated to operation of a positive-locking mechanical elbow.

Wrist rotation

An electric-powered wrist rotator[2] is utilized to provide control of wrist rotation independent of the state of the other prosthetic components. To reduce the effect of the weight of the rotator on the force needed to flex the elbow, the mechanism is placed as far proximal in the forearm as possible, see Figure 1.

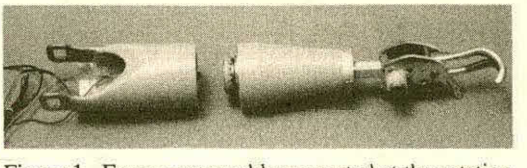

Figure 1. Forearm assembly separated at the rotation joint. The wrist rotator mechanism is in the proximal section (left). The distal section (right) includes a flexion wrist unit at the attachment to the prehensor.

Wrist flexion

Wrist flexion is provided by a positive-locking FW Flexion-Friction Wrist[3] laminated into the distal end of the distal forearm segment, see Figure 1. A molded plastic plate is fastened onto the lock release tab and extends proximally along the surface of the

[1] If an excursion amplifier is not used, then 4 in. (101 mm) of body excursion are needed with a pulling force of at least 15 lb_f (67 N).

[2] Otto Bock Orthopedic Industry, Minneapolis, MN

[3] Hosmer Dorrance Corporation, Campbell, CA

forearm, see Figure 2. The plate increases the effective surface area of the release tab.

The wrist is manually flexed or extended by pressing or striking the plate (e.g. against the wheelchair armrest) with the wrist rotated so that gravity pulls the prehensor and the wrist into the desired attitude.

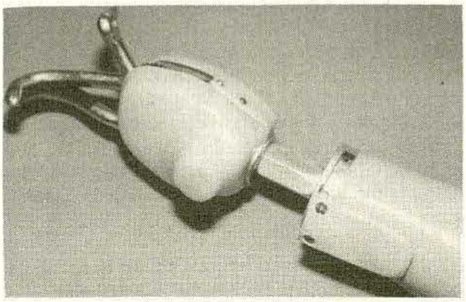

Figure 2. The Intermediate-size Electric Prehensor. The rectangular plate along the forearm is an extension of the lock release tab of the flexion wrist unit.

Prehension
In selecting an electric-powered prehensor, the primary considerations were the component's prehension force and its weight. Through the second author's affiliation, a prototype device, the Intermediate-size Electric Prehensor, was made available for clinical use. The prehensor, shown in Figure 2, incorporates size 10X hook fingers[3] and weighs 7.8 oz (215 gm). A single motor and drive train produce approximately 10 lb_f (44 N) prehension force at the finger tips.

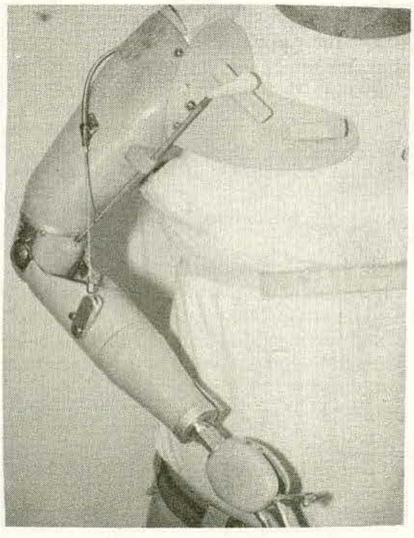

Figure 3. The complete AE hybrid prosthesis. The extended lever arms of chin-operated rocker switches are visible on the pectoral extension of the socket.

Control
The completed prosthesis is shown in Figure 3. As noted previously, the mechanical elbow is operated by flexion of the residual limb coupled with scapular abduction. The control cable is terminated at the lift tab.

The electric wrist rotator and the electric prehensor are controlled by modified rocker switches[2]. The switches are mounted on an extension of the anterior medial aspect of the AE socket and are operated by chin placement.

DISCUSSION

This prosthesis configuration, arrived at through several periods of design and evaluation, underscores the value of progressive, successive fitting of the high-level bilaterally involved individual, especially when other physiological impairments are present. The design at each stage is guided by the person's continuing experiences in non-clinical settings. As a result, the outcome is likely to be more satisfactory to the individual since each design is a response to his or her expressed needs, moderated by personal experience of the characteristics of prosthetic components.

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Effectiveness of a Three-Point Hyperextension Orthosis in Stabilizing Thoracolumbar Injuries: A Biomechanical Investigation

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INTRODUCTION

Injuries to the thoracolumbar region (T11-L2) of the spine are a result of motor vehicle accidents, falls, acts of violence, recreational sports activities, and contribute significantly to the limitation of activity and resultant economic costs. Spinal orthoses have been traditionally used in the management of these injuries treated with or without surgical stabilization. However, the orthotic treatment modality in the management of spinal fractures remains subjective since little objective data are available on the effectiveness of orthoses in stabilizing injured segments. This study utilized a finite element model of the spine to evaluate the effectiveness of a three-point hyperextension orthosis in controlling the progression of deformities at the injury site under gravitational and flexion loads.

METHODS

A Finite Element Model of the Spine

A finite element model of the spine was used for the purpose of simulating the response of spinal segments to external loads. Each motion segment of the thoracic and lumbar spine (T1-S1) was modeled as a linear beam element with end nodes located at the centroids of adjacent vertebral bodies. The overall contribution of all anatomical components was incorporated in the model using a single element stiffness matrix for each spinal segment. Nonlinear effects due to large displacements were incorporated in the model by applying external loads in small increments. Geometric and stiffness properties used in the model represented a normal ligamentous spine with ribcage, and typical sagittal curvatures.

Injury Simulation

The injury model consisted of a two-level injury affecting the T11-12 and T12-L1 segments. An injury of increasing severity was simulated by progressively reducing the bending stiffness of the affected segments relative to the normal value in flexion-extension mode. This was accomplished in the model by progressively reducing the flexural rigidity (EI) value of the beam elements representing the segments with simulated injury.

Interaction of a Spinal Orthosis

The interaction of a three-point hyperextension orthosis with the spine was simulated. The superior pad of the hyperextension orthosis provides resistance to the anterior displacement of the sternum. This constraint is felt by the vertebrae T1-10 since these levels are connected to the sternum via ribs. The effective resistance to anterior displacement at these levels represents the combined (equivalent) effect due to the stiffness of the ribs to posteriorly directed force at the sternum and the stiffness of the orthosis to force applied at the superior pad. The posterior pad is designed to provide a force in the posterior-anterior direction over the injury site. Therefore, the constraints imposed by the posterior pad were simulated at the vertebral levels T11, T12 and L1. The effective resistance to posterior displacement at these levels represents the combined effect of the compressive stiffness of the soft tissue over these levels and the stiffness of the orthosis to force applied at the posterior pad.

The stiffness of the orthosis to forces applied at the superior and posterior pads was determined experimentally. The stiffness of the rib cage to a posteriorly directed force at the sternum, and the compressive stiffness of the soft tissue under the posterior pad were derived using data in the literature.

The model spine was subjected to a distributed axial load of 400N to represent the weight of the body segments above sacrum in the upright posture. In addition, flexion moments of different magnitudes (1Nm and 10Nm) were applied to the first thoracic vertebra. In each simulated condition the resultant angular and translational displacements were calculated at segments with the simulated injury.

RESULTS

Effect of Injury

Both the translational and angular displacement at the injury site increase with increasing severity of the injury. The translational displacement at these segments is in the anterior direction. The angular displacement is in the forward flexion direction giving rise to kyphotic angular deformities.

Effect of a Hyperextension Orthosis

The effect of a hyperextension orthosis on the angular displacements at segments with simulated injury is shown in Fig. 1. The horizontal axis denotes severity of injury, while the vertical axis shows angular displacements at the T11-12 segment. A 100% value corresponds to displacement at the T11-12 segment of an unbraced, normal spine under gravitational load of 400N. Positive displacement values denote kyphotic angular displacements.

For injuries that cause up to 60% loss of segmental stiffness, the brace maintains the angular displacement at the T11-12 segment within the range of values of an unbraced, normal spine (point A). This holds true for gravitational and small flexion loads. However, under the action of a larger (10Nm) flexion moment the kyphotic deformity in the braced spine exceeds the normal values at much less severe injuries; injuries for which the loss of segmental stiffness is only about 25% of normal (point B). With increasing severity of injury, significant kyphotic deformities develop at the injured segment in spite of the brace. Although the T12-L1 segment also undergoes increasing kyphotic angulation with increasing severity of injury, the T11-12 segment limits the load carrying capacity of the injured spine.

Effect of Orthosis Rigidity on Segmental Motion

Displacements at the T11-12 segment in the braced spine are not significantly affected even when the brace stiffness is increased two-fold as compared to the standard Jewet design. At one-half the standard brace stiffness, there is a 20% increase in kyphotic angulation at T11-12 as compared to the deformity in the standard brace. As the brace stiffness is reduced further, as in the case of a corset, the brace rapidly looses its effectiveness.

Loads Exerted by the Orthosis

In addition to calculating the segmental displacements, changes in pad loads were calculated at the superior and posterior pads of the hyperextension orthosis. The pad loads were found to increase with increasing severity of injury, and with increasing flexion loads applied to the spine model.

DISCUSSION

The load-displacement behavior of a spinal segment is affected by an injury and the extent of such effect is a function of the type of injury (e.g., compression fracture, burst fracture, seat belt type injury, and fracture-dislocations). The ability of the injured spine to withstand loads, without causing the progression of a deformity at the injury site, is a primary biomechanical concern in the treatment of thoracolumbar injuries.

For two-level injuries that cause up to 25% loss of segmental stiffness, such as single-column injuries, the orthosis can restore normal resistance to deformity at the injured segments, under gravitational as well as large flexion loads. In loss of stiffness between 25% and 60% of normal, such as two-column disruptions, the orthosis can restore normal resistance to deformity under restricted patient activity level in the brace (low flexion moment). Beyond 60% loss in segmental stiffness, such as severe two-column and three-column injuries, the orthosis alone appears to be ineffective in preventing progression of deformity.

These conclusions are subject to the assumptions and limitations of the study. The simulation model of the spine-orthosis system did not consider an active role of musculature in providing stability to the injured spine. In order to study this role of musculature, an experimental study is being carried out to measure changes in pad loads while subjects perform various tasks such as attempted forward bending, and holding weights in outstretched arms. Results of this experimental study will be compared against the corresponding values predicted by the simulation model. Such comparisons may shed some light on the stabilizing role of the musculature while wearing a brace. Finally, the response of the orthotically supported injured spine to loads in other planes and evaluation of other orthotic designs such as the total contact TLSO is being investigated.

ACKNOWLEDGMENT

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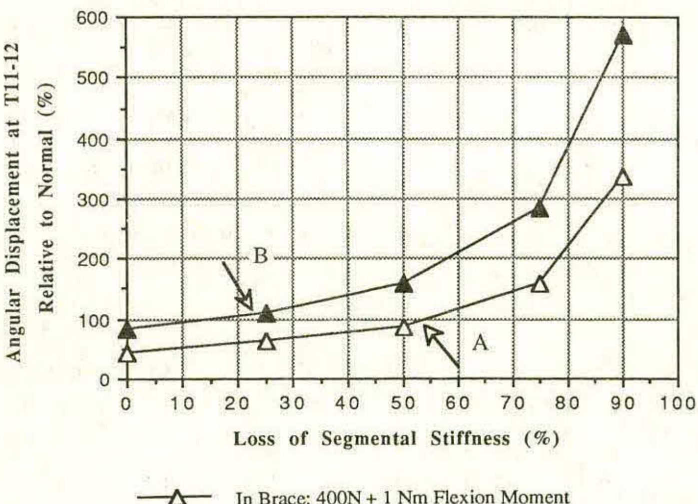

REHABILITATION ENGINEERING AND A CHILD WITH MULTIPLE CONGENITAL AMPUTATION

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ABSTRACT

Appropriate technology must be applied at the right time to assist the young child with multiple congenital amputation to develop as normally as possible. Goals and plans by which technology can be applied to benefit the child are essential. Flexibility in the plan must accommodate (1) failures in acceptance of a rehabilitation device by the child, and (2) new technology which may come on the scene in the future. This paper describes Prosthetic and Rehabilitation Engineering work with a child with deficiencies of all limbs.

INTRODUCTION

A 3 month old baby under foster parent care presented in April 1986 with bilateral above-elbow transverse hemi-melia, amelia of the right leg and proximal focal femoral deficiency of the left leg with dysplasia of the foot. The incidence of such extensive amputation is fortunately low (1). Consequently direct experience in handling such problems is rare. With little available in the literature to guide us, our approach has been to apply strategies applicable to unilateral congenital amputees and some trial and error. The aim has been to promote motor development and skills so that the child can make maximum use of her available facilities to become as functionally independent as possible.

MOBILITY

At age 6 months a "flower-pot socket" with bi-valved body jacket was made to encourage sitting and upright posture. This was later put on casters so that the infant could be towed around to enjoy the sensation of mobility. Physiotherapy was aimed at encouraging normal motor development with emphasis on head control, rolling, sitting balance and posture.

Swivel Walkers

Sitting balance developed rapidly as did our confidence in the ability of this young girl to achieve. The "flower-pot socket" was fitted to the base of an Oswestry Swivel Walker as a first option in self mobility. Skill in moving forwards and around corners and so becoming mobile at home was developed inside a month.

Powered Mobility

Powered mobility was considered the most viable option for future mobility requirements. We believed powered mobility should offer vertical as well as transverse positional capability in order to give the child (a) the independence to get into and out of the mobility device unassisted, and (b) enhanced social, educational and environmental interactions. Devices such as the "Turbo" motorised wheelchair were not available to us so a vertical lift seat module to fit onto a standard power wheelchair base was designed and constructed. A scissor mechanism driven by a power screw was selected for the lifting device because of its compactness. High starting forces to raise the collapsed scissor and extreme non-linear speed and movement charac- teristics of the scissor had to be overcome. A seat projects from the front of the lifting module and forward of the caster wheels of the power base. Controlled vertical movement from floor level to 900mm is possible. The seat supports a control box for activating a security bar, lift mechanism, speed/ direction of the power base. The security bar must swing into place across the child's pelvis before the power base can be driven.

Lower Limb Prostheses

Auto-ambulation was not part of the original prosthetic plan, however this girl's ability to master assistive devices was so impressive and her requests to walk so fervent that there seemed a high likelihood she would succeed in walking on prostheses. A Canadian Hip Disarticulation-type prosthesis was made for her right side and an above knee extended prosthesis for the left. With experimentation and persistence the outcome has been satisfactory. Standing balance while performing upper limb activities, unassisted walking for a few steps and walking between parallel bars or with a walker has been mastered.

UPPER LIMB FUNCTION

The girl has developed considerable skill holding and manipulating objects with stumps, shoulder, cheek and mouth actions. Our inability to match this dexterity at times causes frustration and rejection of prostheses.

It is not considered likely her stumps, particularly the right side will grow in proportion to her body so the present dexterity will not be possible in later childhood; future reliance on prostheses requires that upper limb prosthetic development continue as a major activity. Prosthetic planning has promoted the longer left stump as the dominant limb. Various combinations and designs of prosthesis have been tried however the most effective to date is a right limb prosthesis with friction wrist and hook terminal device used with a naked left stump or a left stump cuff to which implements can be attached (cutlery, hair brush, pencils, etc). The right prosthesis is being used more for stabilising objects during activities with encouragement of greater skill development of the left limb.

OBSERVATIONS

The following comments are based on our experience and observations to date-

1. Multiple amputees require long-term assistance. Taking on a case requires a long-term commitment.

2. As with all Rehabilitation Engineering activities, attempts at providing solutions to complex problems require input from a team who can combine their various skills to achieve a desired goal.

3. The team requires frequent contact with the child and time to observe, to try ideas, make modifications, etc. to achieve a satisfactory result.

4. The child must enjoy the team contact and not feel threatened or intimidated by what is being done.

5. An open-minded approach is necessary to ensure the child is not treated with a "tunnel vision" like attitude. The age of technology offers a brighter future for people with severe physical disability providing prescribers of assistive devices are prepared to keep abreast of technological development and not cling to old technology with which they feel safe and familiar.

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Braided Artificial Muscles: Mechanical Properties and Future Uses in Prosthetics/Orthotics

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ABSTRACT

The history behind the use of braided "McKibbon" artificial muscle actuators in rehabilitation is briefly reviewed. Recent commercial extensions, which emphasize applications in robotics and telerobotics, are documented. Simple fabrication techniques for inexpensive actuator development are outlined. In terms of strength, speed and power, braided actuators are shown to be superior to both traditional pneumatic cylinders and DC torque motors. Conceptually, gas pressure is analogous to muscle activation. The "length-tension" relation is represented by a monotonically-increasing slope and is modulated by pressure. Series elastic properties of muscle can be approximated by placing an elastic element in series with the actuator. As in biological muscle, stiffness changes in proportion to force, and thus joint stiffness can be modulated via co-contraction of antagonists. Our use of these muscles in head-neck-torso and upper-limb anthro-robotic models is discussed. Possibilities for use in powered orthotic and prosthetic are outlined. It is also shown that many of the problems that limited efforts in the 1960's have been eliminated.

INTRODUCTION

The initial motivation behind this work was our desire to create physical anthropomorphic models of human systems that could be utilized for basic studies in biomechanics and motor control. These physical models supplement results from ongoing research projects involving human experiments and computer simulation of the head-neck and upper-limb systems. A rationale behind their creation was that carefully constructed models, complete with nonlinear mechanical properties for ligament, bone, cartilage and muscle that are similar to the appropriate biological tissues, would provide another mechanism for obtaining information on internal tissue loading during voluntary movement tasks and impulsive loading. Additionally, by having computer-controlled muscle actuators, such systems could help test theories in motor control. There is a history for braided pneumatic actuators in rehabilitation (8), although for practical reasons the technology fell out of favor during the 1960's. More recently, however, it has been suggested that pneumatic power has many advantages over electric power, at least for hand power in children (7). New technology and increased availability have eliminated many prior limitations (e.g. power supply, valve technology, control).

In this paper: *i)* a technique for producing simple, lightweight, powerful, and yet inexpensive braided pneumatic actuators is outlined; *ii)* mechanical testing is used to show that the properties of these actuators are similar to those of biological muscle; and *iii)* techniques are discussed for incorporating these devices into prosthetic and orthotic systems.

BACKGROUND

Braided pneumatic actuators, first described in a patient to Morin (1947 in France, 1954 in USA), were introduced to the prosthetics community (apparently independently) by McKibbon in the late 1950's. Conceptually, when an internal bladder is pressurized, loading on the surrounding mesh results in an increase in diameter and in axial shortening. The generated axial contractile force is much higher than for pneumatic cylinders of similar cross-section (8). "Length-tension" curves were found to be similar to those seen for muscle over the physiological operating range, only with pressure replacing activation as the control input (8). After significant initial excitement over these actuators at a conference on *The Application of External Power in Prosthetics and Orthotics (1961)*, there was a loss of interest. This seems to be correlated both to the rising excitement regarding myoelectric systems and to practical problems related to pneumatic power source storage constraints, lack of availability of quality pneumatic valves, and concerns about stability and controllability. These concerns appeared to outweigh noted advantages such as stiffness modulation when used in antagonistic pairs (2).

In recent years, braided artificial muscles, termed "Rubbertuators" (Bridgestone Co.), re-emerged as an important robotic component, especially in Japan. In a related development, Immega (6) introduced a new, ultra-strong actuator termed the ROMAC (RObot Muscle ACtuator). Here an articulating polylobe bladder is surrounded by a flexible, inelastic sheath and an inelastic harness; when under pressure, the latter arcs outwardly and laterally. This results in axial shortening of up to 50% and very high loads. Although impressive, these actuators are bulky and use a large amount of gas, and thus are not be appropriate within artificial limbs. However, ROMAC's have been used for myoelectric control of telerobotic systems, where a rectified and filtered EMG is used to control air pressure (3). With this arrangement, system stiffness can be modulated via antagonistic muscle co-contraction and position via the ratio of activity, similar to theories in motor control (5). The human-machine interface is thus improved. However, both Rubbertuator and ROMAC actuators are quite expensive.

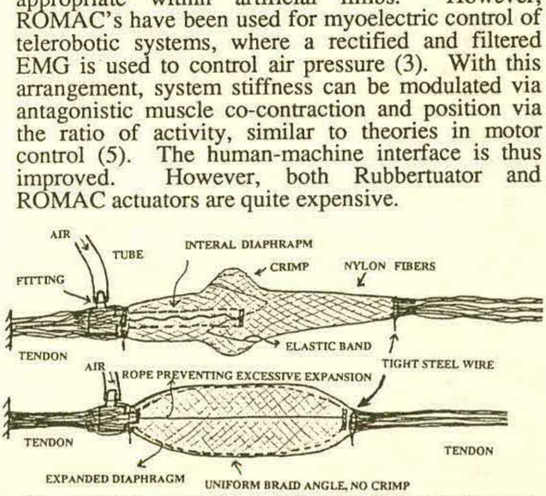

Figure 1: Relaxed (top) and contracting (bottom) actuators

METHODS

Over the last three years we have fabricated a variety of braided actuators that have been used in head-neck and upper-limb anthropomorphic replicas. Of special interest is that inexpensive, lightweight, dependable actuators are possible which have size and strength similar to biological muscle. This will be our focus.

Internal Diaphragm Fabrication. The components of the system are shown in Figure 1. A variety of diaphragms have been tried, including fabricated silicone rubber bladders, latex rubber "balloons", latex tubing, and silicone tubing. There is a tradeoff between dependability (resistance to "popping") and pressure-force linearity (thinner walls preferred). Latex tubing is more dependable, but silicone tubing provides for more linear pressure-force behavior since a wider variety of wall thicknesses are available. Both are in current use. A small nylon rope within the sealed diaphragm is used to limit counter-productive axial expansion.

Braid Fabrication. We have tried a variety of braids, including various fibers, nylon, and polyester. Glass and carbon fibers are inappropriate because of their weakness in shear - they tend to fray. Attempts to implant fibers into silicone rubber failed due to internal friction preventing high force production. The simplest approach is to use readily available nylon hose covering; the amount of braided required per actuator, even for 2-deep braiding as we often employ, is under $1 per actuator. The disadvantage of this inexpensive approach is that the weave angle is essentially pre-set, usually to 20-30 deg. "Crimping" (Figure 1, via reinforced elastic bands) can be used to modulate this effect; during pressurization, these bands quickly become mechanically irrelevant. This allows the initial length to be changed and increases the passive elastic extension, yet at the cost of the amount of contraction. Other designs have been explored (e.g. axial fiber orientations as in (1)), but were discarded due to inappropriate passive compliance and fabrication difficulties. Improvements are possible by allowing non-cylindrical shapes and using strategic harnessing.

RESULTS

We have tested a variety of single- and double-acting traditional pneumatic cylinders (Clippard, Bimba, Festo), an old McKibbon muscle (courtesy of Rancho Los Amigos), a few Rubbertuators, and a variety of our braided actuators. All of the braided, McKibbon-like actuators are clearly superior to traditional cylinders in terms of force per mass, power, and similarity to biological muscle properties (4); these will be the focus. Ideally, the actuator should shorten 40% and passively lengthen 40% with minimal resistance. Length-tension and passive elastic behavior can be modified by changing the default weave angle. Small angles (e.g. 10-20 deg relative to the long axis) result in greater shortening (e.g. 30%) but poor passive extension (e.g. under 10%), while moderate angles (e.g. 40 deg) result in less shortening (e.g. 15%) yet higher passive extension (e.g. 20%). This tradeoff is due to the equilibrium braid angle of about 65 deg.

Dynamic Response. Other properties of biological muscle include force-velocity and series elastic characteristics. The dynamic response time for the actuators is fast; in fact, it is more affected by the supply line length than the actuator. For short supply tubing lengths, the isometric rise time due to a step input in pressure is about 100 ms. Slightly longer times are seen for isotonic movements. These times are similar those for biological muscles. Muscle series elastic properties are a main cause of dynamic impedance modulation (9). Nonlinear series elastic properties similar to those for musculo-tendinous systems are easily produced by placing the actuator in series with a braided structure (e.g. rope).

DISCUSSION

Current actuators are lightweight, powerful, and exhibit mechanical properties that are fairly similar to biological muscle. Response times are fast. Because of the automatic stiffness modulation feature, systems can dynamically interact more effectively with the environment, and furthermore are safer. On paper, devices which are stronger and shorten much more are possible. One area where improvement is necessary is in viscosity modulation (viscosity should increase as stiffness increases). A challenge, definitely possible given current technology, is to place these actuators within prosthetic and orthotic systems. It appears quite likely that these actuators will eventually replace electric motors in such systems. Simpler examples are also easy to envision. Hospital rooms have access to air pressure, and inexpensive, quiet compressors can easily be set up in a home or at school. Active orthotic systems for physical therapy, especially related to contracture prevention, could then be designed and implemented.

ACKNOWLEDGEMENTS

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DYNAMIC TRACTION FORCE AND NECK STABILITY ON THE KINETIC BED

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ABSTRACT

Acute spinal cord injury (SCI) patients are frequently placed in cervical traction on a kinetic bed, which reduces risk of pressure sores and respiratory or vascular complications by continuous side-to-side tilting. In order to test the ability of the bed's lateral supports to maintain spinal alignment and the constancy of traction force, we measured relative head-to-body acceleration during placement and rotation of able-bodied post-acute and acute SCI subjects on the kinetic bed. We also measured traction force *vs.* rotation angle of three different traction devices.

Traction supplied via a sheathed steel cable was found to vary more than either a cord-and-pulley arrangement or a constant-force spring device. Torsional head-to-body motion between the sensor sites totaled 2.9° in able-bodied subjects. Whether such cyclic motion affects clinical outcome is unknown, but it may increase pain felt by patients during turning.

INTRODUCTION

To reduce risk of pressure sores [1] and to manage respiratory and vascular sequelae [2], the SCI patient may be placed on a kinetic bed (*e.g.* "RotoRest", Kinetic Concepts, Inc., San Antonio, TX) that is continuously tilted about its longitudinal axis typically 60° to either side of vertical [3].

Constancy of traction force and cervical spinal stability during turning on kinetic beds is poorly documented. Meinig, *et al.* [4] measured femoral traction force in seven patients during kinetic therapy and found cyclic variation of 50% proportional to tilt angle, in addition to transients due to manipulation by attendants. McGuire [5] and Salciccioli and Kuric [6] made radiographic measurements of neck angulation during turning while in traction, the former on a single cadaver and the latter on actual patients; radiographs showed neck angular motion of 2 to 9°.

METHODS

Measurements were made using 3-axis 5-g range accelerometers assembled from single-axis integrated-circuit devices (model 2021, IC Sensors, Milpitas, CA) in a 1-inch cubical case [7]. These were placed on the front and right side of the head and chest using Velcro and elastic straps (Figure 1). A cable tension transducer (Entran ELF-1000, 50 lb) provided indication of the traction force. Signals were amplified by a DT709-Y signal conditioning board modified for a gain of 50 before recording at 4 to 20 Hz using a DT2814 12-bit analog-to-digital convertor (Data Translation, Marlboro, MA) and IBM PC-XT. Resolution of acceleration was ±0.002 g; force was resolved to better than ±0.01 lbf.

The acute SCI patients were both male, with cervical lesions one and two weeks previously. One had 7.5 lb traction via Gardner-Wells tongs; the other had 5 lb applied to a halo. Two of five able-bodied subjects were female; 5 lb traction was applied via a halter. The weight hanger contributed an additional 1 lb.

For tests of intrinsic variation in traction force, a cable from the weight stack or spring device was attached through the load cell directly to the head restraint, for three force magnitudes (5, 15 and 25 lb). Rotation angle was measured by an accelerometer on the bed frame, expressed as fraction of the maximum of 60°. The sheathed steel cable normally supplied with the bed was compared with a nine-spring constant-force traction unit [8] and with a cord on a swiveling pulley.

RESULTS

Traction alone

These tests measured traction force *vs* rotation angle without complicating factors introduced by movement of the patient on the bed. The range between maximum and minimum traction force for the sheathed cable (Figure 2) is four times that for the constant-force unit:

Weight	5	15	25 lbs
Sheathed cable	0.13 lb	0.24 lb	0.68 lb
Pulley and cord		0.84	
Constant-force	0.04	0.03	0.16

Able-bodied subjects

The second set of tests were of able-bodied subjects at 5° head-up inclination. Figure 3 shows force and head-body difference with sheathed cable traction; figure 4 is with constant-force traction. Both runs have a range of 0.05 g corresponding to about 2.9° torsional rotation of the neck. Figure 3 is roughly symmetrical with rotation angle, returning to near the starting point, while figure 4 has a symmetric motion added to an increasing shift in head angle relative to the chest.

Neither traction method actually produced the intended 5 lbs. The sheathed-cable method ranged from 3.15 to 4.3 lbs and varied only 0.2 lbs during the right half of the rotation cycle, but 1.15 lbs during the left half. The constant-force unit produced 2.6 to 2.85 lbs through most of the complete cycle, with one peak of 3.05 lb; such a momentary peak might be caused by the subject shifting down on the bed.

Acute SCI patients

Both cervical SCI patients on the RotoRest bed had standard sheathed-cable traction, at 7.5° head-up inclination. The vector sum of the three orthogonal accelerometers at each of the four sites varied as follows; if attached to the bed frame, the magnitudes would all remain at 1.0 g regardless of rotation angle:

Sensor	Front	Side head	Front	Side chest
Maximum	1.134	1.032	1.059	1.112
Minimum	0.707	0.829	0.789	0.943

The total head-chest angle difference was similar to able-bodied subjects. In one subject (Figure 5) the traction force varied from 4.4 to 13.5 lbs, the maxima occurring when the bed was near horizontal. The other subject's halo was touching the cable bracket, interfering with sliding of the cable; the patient was later moved toward the foot of the bed. Force varied from 6 to 14.5 lbs, with maxima at the extremes of rotation rather than near horizontal.

DISCUSSION

Testing of traction force on the RotoRest bed confirmed published observations of variation with angular position [4]. In the absence of human body motion, variation using the sheathed cable was not half-sinusoidal as previously thought [8]; rather, at low forces there were multiple peaks (Figure 2), which at higher traction loads merged into two peaks following the extremes of rotation angle.

Reduction or increase of force from a known weight is attributed to friction of the cable as it moves within the sheath: frictional drag is added to the weight when the cable is pulled out and subtracted when the cable moves into the sheath [9]. That such friction occurs is shown by comparison of sheathed cable with cord-and-pulley traction, which used the same 15 lb stack of weights; the starting force was 11.3 lbs for the former *vs.* 15.25 for the latter. With actual SCI patients, traction force ranged from 73% to 225% of the intended value (including weight hanger). If distraction of vertebrae at the injury site varies proportionately (which may not occur due to soft tissue damping over the time interval of cyclic variation), then this finding may have clinical significance.

ACKNOWLEDGEMENTS

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FIGURE 1: Accelerometry Coordinate System

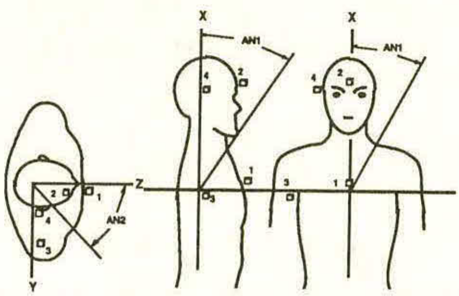


Fig.2 RotoRest Bed Sheathed-cable Traction

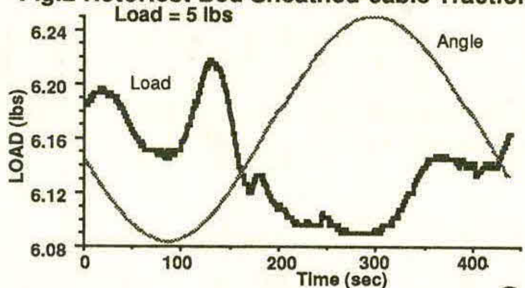


Fig. 3 RotoRest Sheathed-cable Traction

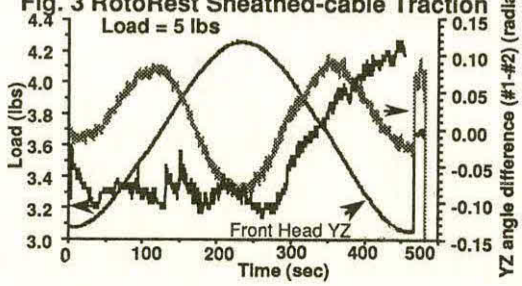


Fig.4 RotoRest Bed Constant Force Traction

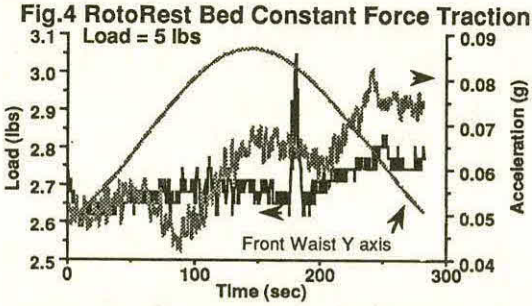
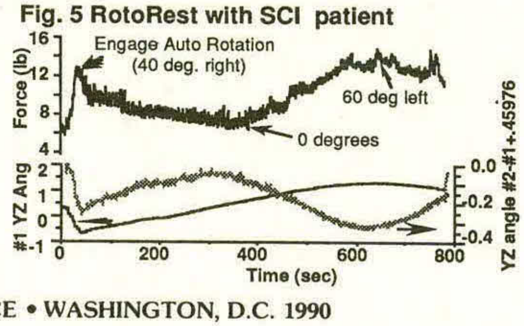


Fig. 5 RotoRest with SCI patient



AIDED COMMUNICATION USING SEMANTICALLY LINKED TEXT MODULES

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ABSTRACT

Communication systems for non-speakers can provide a user with phrases or longer text to speak, but there is a problem in keeping track of large amounts of conversational data and accessing it easily when wanted. A prototype system is described which includes semantic information about stored conversational material. This can assist a user by predicting suitable items and also by helping them navigate through the material they have stored.

INTRODUCTION

Incorporating phrase and text storage and retrieval in an augmentative communication aid is technically not difficult, but in practice the problems of remembering what is stored and accessing it easily have so far proved insuperable. One possibly fruitful approach is to put as much of this administrative burden as possible on the system itself. An aspect of this approach which we have been working on is to examine ways in which stored phrases and text could be part of a semantic structure which facilitates retrieval of this text in a conversational situation.

Other research has investigated the applicability to communication aids of information about the more formulaic and predictable modes of conversational interaction [1]. The project reported in this paper is investigating methods by which reusable material can be recalled when needed. Examples of this type of reuseable conversational material are recent family news, holiday stories, favourite jokes, and, for the non-speaker, a description of their communication system as an introduction for unfamiliar people.

A prototype system is being developed which will have sufficient semantic information to retrieve potentially useful conversational items without the user having to do the equivalent of a database search, while simultaneously trying to hold a conversation. We envision this system will offer predicted texts and focussed searches for requested texts on the basis of minimal input from the user.

DATABASE DESIGN

Most current and proposed search tools require a high degree of cognitive load (identifying what keywords should be used) and physical interaction (typing keywords or controlling a browse tool).

Figure 1 is a diagram of the structure for a prototype system which will incorporate semantic information about the conversational material held in order to assist the user. The system has four components: the storage structure, the knowledge base, the retrieval (or navigational) system, and the environmental settings.

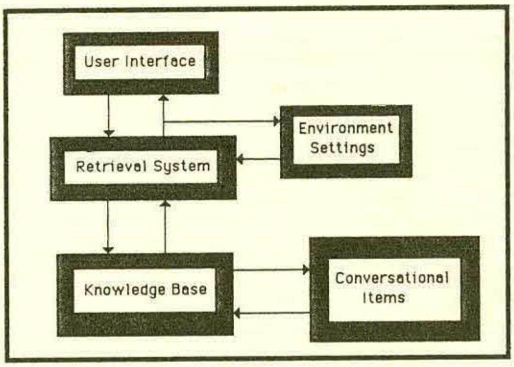

Figure 1 : Diagram of the full system

The user interface to the retrieval/ navigation system presents the user with predicted items during the conversation, and also assists them in searching for an appropriate item. Conversation items are stored in a conventional database format shown in Figure 2. The retrieval/navigational system consults a semantic network in the knowledge base which interrelates elements of the stored conversational items. A portion of such a network relating to the items in Figure 2 is diagrammed in Figure 3. The knowledge base represents part of the user's world knowledge and allows both automatic retrieval and guided navigation of the stored conversational items. The retrieval of a specific conversational item updates the environment settings which also play a part in finding probable choices for the following conversational item.

PROGRAM DEVELOPMENT

As the development of even a modest knowledge base is a considerable task [2,3], the intention is to begin with modelling particular conversational settings and segments. Developing methods for categorisation and labelling of semantic information is also an important part of the current investigation. Preliminary work is being done on the Macintosh using the Prolog development environment. This involves the implementation of a small prototype of a conversational device which will include the features mentioned above. The prototype will reflect a conversational knowledge base for one of the authors, and as such, will illustrate such a system as it might actually be used.

FUTURE DEVELOPMENTS

This project is part of a larger investigation into incorporating reusable conversation items into an AAC system, the intention of which is to take much of the cognitive load from an AAC user, leaving them freer to participate fully in conversations. The knowledge gained in this research will also augment other work in our department on suitable interface design, and other applications of artificial intelligence techniques to AAC systems.

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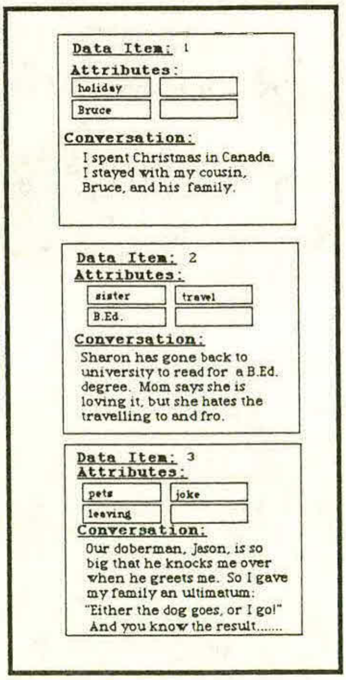

Figure 2 : Examples of stored conversational items

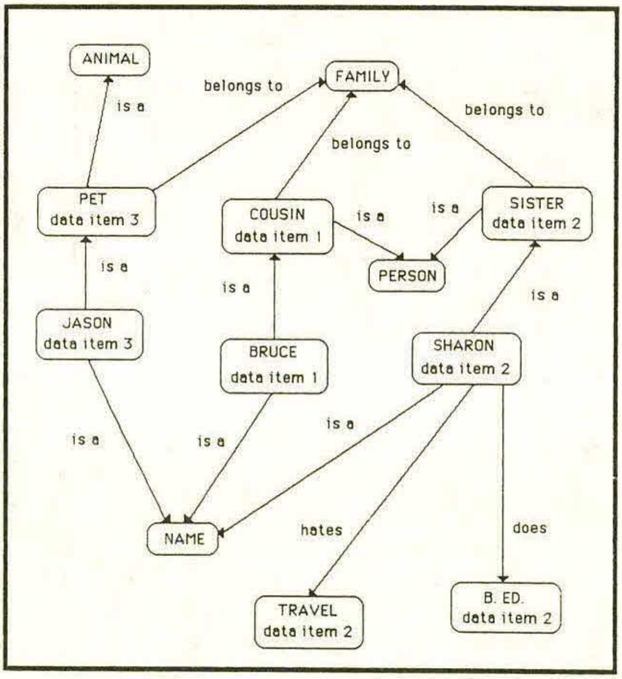

Figure 3 : Part of the semantic net in the knowledge base

Adapt: an authoring language for a flexible AAC architecture

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Introduction

The augmentative communication system architecture project at the University of Delaware and the A.I. DuPont Institute has three primary intended products:

1) the definition of a flexible software architecture for augmentative communication systems (Demasco, 1989; McDougal, 1988);

2) a collection of software modules, which will be made available for use by other communication system developers (Demasco, 1990), and

3) a complete augmentative communication system which can serve as a basis for extension and experimentation.

The software architecture defines the interfaces between the key components in a communication system. A primary goal of the architecture is to allow many useful enhancements or modifications to be made to the base system as extensions, without having to make major internal modifications. This goal interacts with the critical communication system requirement that both clinicians and system users must be able to customize the behavior of the system to meet their needs. These relatively superficial customizations involve the setting of system control parameters and modifications of the content or structure of the system's vocabulary set.

Both sets of goals have been addressed by moving much of the system control into an interpreted, user accessible authoring language. This software structure enforces a clear separation between module implementations and their interconnections. System modules are written in C++ (Stroustrup 1986; Eckel 1989), using an object-oriented design approach. This approach makes these modules relatively easy to modify, however extensions at this level still require a detailed understanding of C++ and the interfaces of at least some of the objects previously defined in the system.

The basic system modules are interconnected by scripts to build a functioning communication system. The authoring language provides a simple interface to the capabilities of the underlying modules without exposing all of their implementation complexity. The language must be powerful enough to control the overall communication system, yet simple enough to encourage experimentation with new ideas by developers, clinicians, and users.

The authoring language

The design of the language, named Adapt, has been modeled after LOGO (Papert 1980, Burns 1986). LOGO was chosen because of its demonstrated accessibility to inexperienced programmers, and widespread familiarity in the educational community. Language constructs are quite simple, with a minimum of syntactic requirements, yet the language is sufficiently powerful to express complex system control policies in an understandable fashion.

The basic language units are calls to procedures which are either primitives made accessible from the underlying C++ modules, or calls to other Adapt procedures. Programs can declare local or global variables and use them to hold simple numeric or string values, references to C++ objects (e.g. vocabulary set entries), or lists of other values. Expressions are built using infix operators and function calls. Control constructs include a LOGO-like counted REPEAT, an infinite LOOP which can be terminated with EXITLOOP, and a simple IF/ THEN/ELSE statement.

Adapt scripts can also define new procedures, which can take parameters, return results, and make recursive calls. The following script:

```
to gcd :a :b do
  if :b == 0 then
  return :a
else
  return gcd :b (:a % :b)
end
```

implements Euclid's algorithm for finding the greatest common denominator of two integers. (All local variables, including procedure parameters, are prefixed with ':', and the infix remainder operator is invoked with '%'.)

Control of the communication system lies within the authoring language, which produces vocabulary displays and implements selection techniques. In addition, the selection of a vocabulary item invokes the Adapt script associated with that item, which can then generate output or take other actions.

System Customization

The authoring language provides a convenient solution to the requirements for minor customization of system behavior by the clinician or user. System parameters are made adjustable simply by providing an

Adapt primitive to update the relevant internal module variables. The initial system script can be edited to adjust any system parameter and thereby achieve a particular configuration. A users' initial customization script also serves as a user profile since the system configuration can be reset to that user's preferences simply by loading the script.

Since scripts are represented as text files, the inclusion of text editing operations in the communication system is sufficient to provide the disabled user full access to this customization capability.

System extensions

Because central control in the communication system resides in a script, larger system modifications can also be made at the script level. A new selection technique, perhaps one designed to take full advantage of the capabilities of a specific individual, or to make use of a new input device, can be programmed in the authoring language. The same mechanism can be used to adapt the system to tasks other than direct communication. For example, the Adapt procedure given below implements a simple communication tutor, which asks the user to produce specific sentences, then checks to make sure they are correct:

```
to Train do
 :prompt = "Form the sentence: "
 :questions =
    [ "I am happy."  "How are you?"
      "Tomorrow, it will be cold" ]
 SetVoice Teacher
 loop
   if emptylist? questions then
     exitloop
   endif
   Speak :prompt
   Speak First :questions
   loop
     :item = Select
     AddToBuffer :item
     if ispunct? :item then
       exitloop
     endif
   CheckAnswer (first :questions) GetBuffer
   ClearBuffer
   :questions = rest :questions
 endloop
end
```

Language extensions

Developers can also extend the authoring language itself by defining new Adapt primitives. Primitives are implemented with procedures in C++, and must therefore conform to the conventions and interface specifications of the existing modules in the system. However, a modular and object-oriented organization (Meyer, 1988) minimizes the proportion of the existing C++ code which must be understood to define a new primitive.

In many cases, *none* of the existing C++ code will need to be modified. The new module declares Adapt *verbs*, which are C++ objects that fit into the language structure by inheritance, and which use existing system routines to interact with the execution environment. Once the new module is compiled and loaded with the existing system, the new primitives can be invoked from an Adapt script.

Status

A prototype communication system which demonstrates the use of Adapt scripts for both overall control of the system and as actions associated with selections, is currently under development. Some C++ modules from this prototype, including the Adapt interpreter itself, will be made available to other developers by the fall of 1990.

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SMALL TEXT CORPORA IN CHARACTER DISAMBIGUATION FOR REDUCED TYPING KEYBOARDS

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ABSTRACT

Character disambiguation for reduced keyboards has been performed using quad-grams derived from large text corpora. It is now shown that smaller corpora are sufficient for this purpose, making system development easier, and introducing the possibility of adaptive modelling for higher efficiency.

DISAMBIGUATION FOR REDUCED KEYBOARDS

Reduced Typing Keyboards

Reduced keyboards are text-typing keyboards with fewer than 26 keys. Their purpose is to make typing easier for handicapped persons who can select directly from a small number of targets (e.g. large switches). Several alphabetic characters must be allocated to each key, however, because there are fewer than 26 keys available, so a disambiguation method is required to identify the exact character implied by a key press. Typical reduced keyboards are based on telephone keypads and contain 12 keys, with up to 3 alphabetic characters per key.

Character Disambiguation

Character disambiguation techniques have been developed (1,2,3,4,5) to enable text to be typed on reduced keyboards. A user types text by pressing the appropriate key for each character, and the automatic disambiguation system attempts to identify the correct character from known statistics of character sequences in the relevant language, and offers this character to the user. The user either accepts the predicted character (by moving on to select the next character of the text) or rejects it by pressing an "Error" key, whereupon the disambiguation system predicts the next most probable alternative character for the pressed key. The user presses "Error" until the correct character is predicted. If 3 characters are allocated to each key, no more than 2 "Error" selections are required to achieve selection of the correct character. Optimal keying efficiencies of 1.1 key/char (keys/character) in English (1), and 1.2 key/char in Dutch (5), have been achieved in simulation experiments.

N-gram Based Character Prediction

The principal method of disambiguation is to use tables of n-grams (sequences of alphabetic characters) extracted from large samples of real text (text corpora) to enable the system to predict the next most probable character to be typed. Mono-grams are single characters, bi-grams have 2 characters ("th", "ea") and tri-grams 3 ("thi", "ead"). Existing disambiguation systems (1,5) are quad-gram ("thir","eady") based. The disambiguation accuracy, and hence the keying efficiency, is greater for higher-order n-grams, at the cost of a disproportionate increase in storage requirement for the much larger number of n-grams.

Quad-gram tables for existing systems were derived from large text corpora: 750,000 English words from the Brown Corpus (6) and 1 million Dutch words from the Eindhoven Corpus (7). The purpose of the work reported here was to investigate the use of a smaller text corpus in the development of an n-gram disambiguation system, in order to make such development easier, particularly for situations where large corpora are not available or difficult to obtain.

N-GRAM EXTRACTION FROM SMALL TEXT CORPUS

Small Text Corpus

N-grams were extracted from a relatively small, restricted-domain text corpus (a 50,000-word thesis). All mono-, bi-, and tri-grams were extracted, those quad-grams occurring more than thrice, as well as those quin-grams (n=5), and some hex-grams (n=6), with a space in the penultimate character. The lower-order n-grams were included to give alternative predictions when the quad-grams failed, which must occasionally occur given the small size of the original corpus. The selected quin-grams and hex-grams were included (at modest memory cost) to try to improve prediction efficiency on word-initial characters, where prediction is most difficult (1). There were 19,202 n-grams, in total, of which 11,038 were quad-grams.

Keyboard Layouts

Two 12-key keyboard layouts, "Alphabetic" and "TOC" (Fig. 1), were derived from the previous research (1,5) on English ("TOC") and Dutch ("Alphabetic"). Slight modifications have been made to include Period and Comma on both keyboards, and a Shift key (#) gives access to non-alphabetic characters. Multiple pushes of Shift allow selection of a full range of Ascii characters.

abx	def	ghi
okl	mnj	pqr
s.u	vwc	yzt
*	0	#

a) TOC Format

abc	def	ghi
jkl	mno	pqr
stu	vwx	yz.
*	0	#

b) Alphabetic

* = Space & Comma, 0 = Error, # = Shift.

Figure 1. Layouts of Reduced Keyboards.

Simulation experiments were conducted in which the disambiguation system counted the number of key-pushes which would be needed to type known texts on these keyboards. The **keying efficiency** was defined as **(No. of key-pushes)/(No. of characters in text).** There were 4 texts: 2 from the text corpus, 1 from a novel and 1 from a philosophical work. The shift mechanism enabled all the characters in these texts to be typed.

The simulations were conducted with (a) quad-grams only, (b) mono-, bi-, tri-, and quad-grams, and (c) all available n-grams (from mono- to hex-gram) in the disambiguation system. The effects of the lower- and higher-order n-grams were thus established.

KEYING EFFICIENCY RESULTS

T	Quad Only		Mono-Quad		Mono-Hex	
	TOC	Alpha	TOC	Alpha	TOC	Alpha
A	1.22	1.25	1.15	1.18	1.14	1.17
B	1.34	1.36	1.21	1.23	1.21	1.22
C	1.19	1.22	1.12	1.15	1.12	1.15
D	1.12	1.14	1.10	1.12	1.09	1.11

T=Text. Texts A & D were corpus extracts.
Texts B & C were non-corpus texts.

Table 1. Keying Efficiency (Keys/Character)

The best efficiency was produced by a text (D) extracted from the original corpus, and the worst was produced by the non-corpus text (B) from the novel. Text B contained many punctuation characters which necessitated use of the shift key, and hence impaired efficiency. Text C (non-corpus) was better than A (corpus), however, which indicates that the n-grams can perform well with unrelated texts. The higher-order n-grams (n=5,6) made only a slight improvement. The lower-order n-grams (n=1,2,3) improved the efficiency by between 1.8% and 9.7%, and so proved worthy of inclusion. The TOC keyboard performed better than the Alphabetic by a small margin. The Alphabetic layout may be easier to learn, however.

CONCLUSION

The system efficiency was very similar to that attained in earlier work (1,5), so it is feasible to derive n-grams from a relatively small learning corpus. This also indicates that an adaptive model (i.e. one which learns its n-grams from the user's input) could function well in this application, because the user would not need to enter a large body of text to optimise the n-gram model. Higher keying efficiencies may be possible with an adaptive model.

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Intelligent AAC Systems: What Can Be Done Now

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Introduction

With the advent of smaller, more powerful computers, it is becoming possible to develop AAC systems which take advantage of Artificial Intelligence and Computational Linguistics techniques. In particular, we envision the development of an "intelligent" AAC system that can *understand* the operator's input well enough to infer what words or syntactic structure may be omitted or missing, enabling the device to output a complete and correct sentence from partial input. At some point in the future it may be possible to create an AAC system with all of the linguistic knowledge of a human speaker, but the limitations of existing theory and technology allow only a small subset of that knowledge to be incorporated in current systems. In this paper we explore some of the possibilities for AAC systems that could be developed given the present state of affairs. Of course, each of the possibilities must contain trade-offs of one kind or another. We discuss various populations of potential AAC system operators and show how different populations would benefit from different aspects of "intelligence" in their system.

Potential Operators

Hundreds of thousands of people could benefit from Artificial Intelligence in electronic communication aids. This population is heterogeneous and dispersed. Nevertheless, certain groups do cleave together. A discussion of two of these groups can illuminate the considerations involved.

One group includes ambulatory, cognitively impaired adolescents with severe language disability. Consider a 14-year old boy with Down's Syndrome, who has a language age of 4 years and 8 months. His actions are socially appropriate, he has frequent communicative intent, but does not speak and has failed to master signing. His vocabulary needs for school and daily living activities might include 50-75 function words and at least 300 content words. Such an operator would be willing to allow a communication device to determine the syntactic organization of his utterances. The finer points of style and pragmatics are less important to such a person. He may even acquire some syntax and independent speech through observation of his device's output.

Another group includes cognitively intact, educated adults who have recently acquired a severe speech impairment. Consider the situation of a 44-year old female lawyer. She has suffered a brain stem stroke and is cognitively normal, yet physical disabilities preclude all but row-column scanning access to a communication aid. We might think that a template system giving access to very rapid yet general language would meet this individual's needs. Her perceptions would probably be different. Cognitively intact individuals who have few opportunities to communicate want complete control of their language in each communication opportunity. Style and pragmatics are of paramount importance to users in this group, who would be unwilling to have the communication device provide the overall organization of their utterances.

System Knowledge Sources

We envision systems in which operators will choose partial representations of their final communicative intentions using some input paradigm. It will be the job of the system to "understand" the intended meaning and eventually generate a well-formed utterance based on this meaning (Baker, 1982), (Demasco et al., 1989). Since the system's knowledge of the discourse context will be incomplete, however, there is a possibility that there may be more than one interpretation of the input.

Consider the following input: "ate duck". Notice that this is certainly not a well-formed utterance. However, one may be able to infer the intended meaning by taking into account various sources of knowledge.

Semantic Knowledge -- information about the semantic categories of the words involved would be helpful in determining what role was being played by each word. For instance, knowing that "ate" is an action performed by animate objects might lead one to conjecture that the intended utterance was "The duck ate".

Pragmatic Knowledge -- knowledge about the discourse situation might aid in inferring the intended meaning. For instance, if the preceding discourse has been discussing John and what he did last night, a more reasonable rendition of the input might be: "John ate duck". The assumption on the user's part was that the agent of the eating could be inferred from context.

Notice that as more sources of knowledge are applied, the system is able to do more inferencing toward the intended meaning. This, in turn, allows the user to provide less information about his/her intended utterance. At the same time, as the system does more inferencing the user is given less control over the actual utterance.

The above example shows a rather simple sentence in terms of its syntactic structure. It is a simple declarative sentence with simple noun phrases. Such a sentence may require little inferencing on the part of the system because it contains only one main verb and its simple noun phrases are given in canonical order -- usually AGENT-ACTION-THEME. Ambiguity resolution can become more complicated if the input is intended to be realized by more complicated syntactic structures.

Consider the problems with allowing syntactic structures which do not maintain canonical word order (such as a passive sentence as in "The duck was eaten by John"). Notice to generate these sentences the system may not assume that the input given by the user is AGENT-ACTION-THEME but must infer the role being played by each noun phrase. In addition, the system must have some reason for choosing to use a passive sentence over a simple declarative sentence.

The user may be able to provide the system with some information to help avoid extensive inferencing. For instance, in the above case, the system and user might follow the convention that all input will be given in canonical order, but a special marker will be used to indicate a passive sentence is desired. Of course, following such a convention may be difficult or impossible for some user groups.

The addition of relative clauses (as in "the man *that knows my father* helped me") adds a great deal of complication because the input from the user may now contain two verbs -- one to be taken as the main verb of the sentence and the second to be part of the relative clause modifying one of the noun phrases of the main sentence.

As the list of possible syntactic structures grows, the job of the system becomes more complicated. With the added complication comes the potential for ambiguity which, without aid from the user, may not be resolvable by the system given the current state of affairs in computational linguistics.

Fitting the System to the User

If we are to develop an intelligent system given today's technology, decisions must be made concerning both permitted syntactic structures (the more complicated the more powerful the inferencing must be) and the permitted semantic sophistication (the more complicated/extensive the domain of discourse the more detailed the required knowledge must be) and the locus of control given to the user (some of the inferencing required by the system can be eliminated by requiring the user to be more explicit about intended meaning).

If we consider the first operator group discussed, it is clear that an AAC system must assume a great degree of control and perform a large amount of inference to produce a correct utterance from a few content words entered by the operator. Such a system may not be able to provide much syntactic sophistication, and its word list may not be that extensive, but it can certainly meet the needs of operators in this group by cutting down on the number of actuations required for communication and producing a correct sentence from partial input.

If we consider the second operator group, we see that an AAC system must address a different need, cutting down on physical actuations without taking too much control from the user, who is still free to determine the overall structure of each utterance. This user will demand syntactic sophistication from the system as well as a large word list. This system will require that the user follow conventions for marking various syntactic desires so that the system can generate the intended utterance and the user can be saved the physical hardship that would be required to fully specify the utterance. On the other hand, this user is quite capable of following the necessary conventions. For her, it is a small price to pay in order to maintain control and still get the desired sophistication within a relatively short amount of time.

Conclusions

While current technology in Artificial Intelligence, Linguistics, and Computer Science will not allow us to build a vastly intelligent AAC system containing sophisticated syntactic, semantic, and pragmatic capabilities, it is possible to provide systems with limited intelligence. In this paper we have shown that this intelligence must be tailored to the wants and needs of each particular group of potential users.

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Word Prediction Using a Systemic Tree Adjoining Grammar

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Introduction

Several augmentative communication systems attempt to predict the most likely input from the user in order to make that input available with minimal time/ effort. To date these systems have relied on frequency data (e.g., word frequency statistics, word category statistics) However, none of them have employed the approaches developed in linguistics or computational linguistics to the fullest power. In this work the application of several of these approaches to the area of word prediction is investigated.

Background

AAC systems with predictive capabilities can potentially increase communication rate for non-vocal users. Word prediction systems typically present a list of likely words to the user. This list is based on previous user input and general linguistic knowledge. Early word prediction systems relied on word frequency statistics (Gibler, 1983). Typically, these systems used initial letter selections to constrain the possible choices from a frequency ordered dictionary. While this approach did offer rate enhancement over traditional spelling systems, the use of additional linguistic information could potentially improve the accuracy of predictions.

Syntax was used to enhance the predictive system PAL (Arnott, 1984) (Swiffin, 1987). It maintained a table of probabilities for all possible pairs of word categories such as adjective-noun, verb-noun, etc., and used these probabilities, in conjunction with word frequency data, to compute the probability of the next word. For example, after an adjective is introduced in a sentence, the probability of a specific noun as its successor is computed by multiplying the pre-computed probability of an adjective-noun pair and the noun's static frequency.

While PAL's addition of syntax was somewhat successful, the researchers reported only small improvement in prediction accuracy (4.3% to 6.4%). This modest gain was attributed to a number of factors including the size of the dictionary. The system was somewhat inaccurate because many words belong to more than one syntactical class; yet the system always assured the most frequent class assignment. Inaccuracy also derived from the small scope of application of syntactic knowledge. The authors suggested increasing the transition matrix to three dimensions (i.e., prediction based on 2 previous words) to improve the scope limitation.

A more refined model of syntax (e.g., one that parses the entire sentence using a grammar of English) would certainly increase prediction accuracy. It would allow the entire sentence preceding the current word to be taken into account to yield more efficient statistics. For instance, a noun at the beginning of a sentence is likely to be followed by a verb; a noun following a verb is very unlikely to be followed by another verb. This could be captured using the more global context suggested here.

Ultimately, however, the use of syntax is limited by the fact that it only provides information about sentence structure. It would be advantageous to consider semantic and pragmatic information. In addition, to incorporate advanced syntax semantics and pragmatics into a predictive system, it will be necessary to go beyond a purely stochastic paradigm (e.g, frequency tables) and utilize rule-based formalisms from the field of computational linguistics.

Proposed Work

One goal of this work is to improve predictability of the next word in a sentence by considering a number of linguistic information sources. To improve prediction using syntax, we turn to a standard computation oriented grammatical formalism such as described in (Allen, 1987) and (Winograd, 1983). While incorporating any such theory is likely to improve the situation, it still leaves much to be desired. For instance, consider a situation where *If you do that again, I will smack...* is uttered and the system must predict the next word. Syntax alone can predict that a noun phrase will follow. However, if semantics is also taken into account, the system can predict that the noun phrase will most likely be a person.

Systemic grammar (Halliday, 1985) which has been developed by Halliday and other researchers is a formalism which provides information about many aspects of language. It views an utterance as some meaning whose expression will vary depending on the situation. Thus, it takes into account the semantics of the intended utterance as well as such things as the relationship between the speaker and hearer.

While the above aspects of systemic linguistics make it very attractive for use by a prediction system, in its present formulation systemic linguistics does have its draw-backs. In particular, while the aspects noted in systemic linguistics do affect the syntax chosen for the intended utterance, systemic linguistics itself has no formal explicit treatment of syntax. In this work we propose to augment the systemic grammar framework with a formal syntactic component. In particular, our investigation has led us to Tree Adjoining Grammar (Joshi, 1983) as a formalism which is particularly well suited for this task.

In systemics, an utterance is made by going through a system of choices, each of which can be a choice at different strata; situation, semantics, or syntax. Selecting a particular choice on higher stratum affects the choices on lower strata, i.e., selecting a choice narrows down the possibilities for how the meaning can be conveyed. For instance, the above utterance might result from a mother attempting to warn her child to stop doing some activity. Given the relationship (e.g., mother-to-child) a particular semantic choice (e.g., *if further activity, physical warning to the hearer*) is made, which is a mild physical warning. This semantic choice is made because the relationship (choice at situation stratum) is mother-to-child.

In order to use this formalism for prediction we must take the utterance made so far and infer which choices in the grammar must have been taken in order to get that partial utterance. The predicted next word must also be consistent with these inferred settings.

Compared to systems equipped with syntax alone, the prediction power of this system is substantially increased. For instance, using the same example above, the blank can be predicted to be a noun phrase because that is the only syntactic category consistent with the syntactic choices made so far. As explained above, semantics helps predict that the noun phrase be a person for the same reason.

With systemic grammar it is possible to go even further because situational strata of systemic grammar takes the patterns of utterances into account. This may allow it to infer the appropriate situation (e.g., mother-to-child control). If this is the case, the system can predict that the person should be *you*.

Conclusion

In this work the use of TAG as a formal syntactic component in a systemic grammar framework has been investigated. The work has then been applied to word prediction in the augmentative communication. With systemic grammar it is possible to infer a more global setting by taking into account a piece of linguistic information which appears in a partial utterance. The inferred setting then can be easily used to aid in the prediction of the next word/phrase. Systemic grammar is useful in this task because only certain choices can be made depending on a particular setting.

We intend to implement a prototype system using NIGEL (Mathiessen, 1984), an implementation of systemic grammar which was developed at the Information Sciences Institute. The system will take an input from the user and provide a list of words/ phrases which are predicted by taking several aspects of the input into account.

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A Domain Independent Semantic Parser For Companssion

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Introduction

This work is part of an augmentative communication project being conducted at the Applied Science and Engineering Laboratories at the University of Delaware and the A.I. duPont Institute. The goal of this project is to increase the communication rate of physically disabled individuals via Natural Language Processing techniques.

We wish to take as input a compressed message (i.e., one containing mainly the content words of the desired utterance) from the disabled individual and yet pass a syntactically and semantically well-formed utterance to a speech synthesizer or text preparation system. At the same time, we wish to do this by placing as little a burden on the user as possible (Demasco et al., 89). Thus, we are not interested in a simple coding system (cf. (Baker, 82)) where sentences have been stored and are simply indexed by their content words.

The system is broken into several phases. The first phase, the *semantic parser* (see also (Small&Rieger, 82)) is responsible for determining the semantic role being played by each input word. It must determine which word is the verb, what role each noun phrase plays with respect to the verb (e.g., actor, theme), and what modification relationships are present. The resulting semantic representation is then passed to the *translation component* which is responsible for replacing the semantic terms with their language-specific instantiations. The final phase of the processing is a sentence *generator* which forms a syntactically correct sentence. This paper is concerned primarily with the semantic parser.

Knowledge and Processing

In (McCoy et al., 89) we reported on a semantic parser which relied primarily upon the domain of discourse. As the lexicon grew, this solution seemed unsatisfying because it was difficult to constrain the domain of discourse, and the knowledge management for an arbitrary number of possible domains proved unwieldy. A new approach is being developed which identifies the roles that words can play in a domain independent manner.

The problem faced by the parser is the ambiguity resulting from the compressed input because it contains no syntactic information. Consider the following input: "John study red house". The first problem faced by the system is determining the function of each word in the sentence. Each individual word can have different semantic classifications and thus its function in the sentence may be ambiguous. For example, the word "study" has two meanings: an action, as in "John studies", or a location, as in "John is in his study". In order to recognize all possible word meanings (and to constrain further processing) we classified all words into five categories according to the different semantic functions that the word can play: Actions (verbs), Objects, Descriptive Lexicons (adjectives), Modifiers to the Descriptive Lexicon (adverbs), and Prepositions. Within each category, we further classified the words so that finer semantic distinctions can be made.

If each individual word is looked at in isolation, it (usually) has many interpretations. However, if the input words are taken together, then many of the interpretations can be eliminated. In the above example, while "study" may either be an object or a verb, no other word in the sentence occurs in the verbs hierarchy. Thus "study" will be taken as the verb.

Once the verb of the sentence has been determined[1], additional knowledge sources can be applied to further reduce ambiguity. The main verb predicts much of the structure of the sentence. It dictates, in a top-down fashion, which semantic roles are mandatory and which roles should never appear, as well as type information concerning possible fillers of each role. For example, the verb "go" cannot have a THEME case in the semantic structure. Furthermore, it cannot have a FROM-LOC case unless it also has a TO-LOC. This information is captured with frame predictions which are associated with each verb in the verbs knowledge base.

Based on the particular verb, a set of semantic structures (called frames) is created. Each frame encodes one possible interpretation of the current sentence and contains typed variables which may be filled with words from the input. Each variable type corresponds to a type of possible input word (i.e., they are types taken from one of the system knowledge bases).

For example, the frame associated with the word "study" indicates that the AGENT must be human and that it can take a THEME (some abstract or physical object) and a LOCATION (a physical place). The

1. In the case that the system identifies more than one word that can fill the role of the main verb, it will spawn an independent process for each verb candidate.

AGENT is required while THEME and LOCATION are optional.

Once a frame has been chosen, bottom-up processing attempts to fill out the frame by fitting the input words into the appropriate slots. A frame is considered satisfactory if all of its obligatory roles can be filled.

A final source of ambiguity must be dealt with. So far we have considered words of the input modifying the verb by planning a role with respect to it. We must also consider the possibility of one word of the input serving to modify the meaning of another input word. Because a certain word can only modify certain types of other words, we attach words which can be modifiers onto the words of types that they can possibly modify. For example, the word "red" is attached to the type PHY-OBJ (PHYsical-OBJect) in the object knowledge base. Therefore, the word "red" can modify the word "house" since "house" is a PHY-OBJ, but cannot modify the word "idea" since "idea" is not. Using the modifier information the system attempts to associate any modifier words with the words of the input that they modify. In this way, the "red" from the input will be attached as a modifier to the word "house".

Using the above processing and knowledge sources the parser will come up with two possible interpretations of the input: "John studies at the red house" (here the red house is taken as a location) and "John studies the red house" (here the red house is taken as the thing that John is studying). Notice both interpretations account for all input words and fill all obligatory roles associated with the chosen verb.

Current Functionality

The current system is able to recognize different uses of a verb depending on the modifiers present in the input. Consider "John look Boston" and "John look tired". Respectively, the final outputs are "John looks at Boston" and "John looks tired". Notice that "look" can be used in two very different ways. The system determines which use is intended by considering the rest of the input. If there is an OBJect or LOCation to look at, then the first use is recognized. If this is not the case, but a modifier that may modify the agent occurs in the input, then the second use is recognized.

As an example of how the entire input is used to constrain possible interpretations, consider "John study weather university". Notice that in isolation "university" could either be a LOCATION or a thing being studied (a THEME). However, since "weather" can only play the THEME role with respect to "study" the system correctly generates: "John studies weather at the university".

In addition, the present system has the capacity to infer the verb intended by the user. The present system chooses between *have* and *be* as verb candidates depending on the given input elements. Given the input "John tired", the final product is "John is tired". Given the input "John paper", the final output is "John has the paper".

This system will also infer the actor (subject) of the intended sentence. In particular, if no agent is given, the system will infer the user to be the agent (and thus generate a first person pronoun for that slot). Given the single-word input of "hungry," the system will determine the intended verb and the intended agent, and generate the sentence "I am hungry".

Conclusion

A prototype implementation of the system has been completed and is currently being evaluated. The lexicon currently contains several hundred words of various types. The implementation is in Common Lisp and runs on several different hardware platforms. The evaluation currently includes a paper experiment to determine whether or not the current system mirrors the action of a human. Future plans for evaluation include testing the prototype system with potential users.

Acknowledgments

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IMPLEMENTATION OF AN 8086 BASED OPTIMAL ADAPTIVE CONTROLLER FOR ELECTRIC WHEELCHAIRS

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I- Introduction

A microcomputer based optimal adaptive controller has been previously designed and implemented to provide electric wheelchairs with a reliable and efficient controller that guarantees, not only stable and near optimal response for users of different weight, but also a totally secure and comfortable performance for users with different handicaps [1,2]. While the results of this project were very satisfactory, the inherent limitations of the aging hardware used (Z80 processor) made it essential to upgrade the system using a more efficient and powerfull microprocessor such as the 8086 family of processors. The new implementation, presently under way, not only endows the adaptive controller with a highly reliable and efficient environment flexible enough to allow major additions or modifications, but also an environment which will almost certainly be compatible with future products (software or hardware). Thus, in addition to increased reliability and improved performance, the cost of updating and improving the controller to take advantage of existing technologies will be kept to a minimum.

II- State of the art microcomputer implementation

The heart of the system is an LPM-SBC40 8MHZ V40 single board computer equipped with 512 Kb of on-board memory, an interrupt controller, a serial counter unit and two serial I/O ports both with RS-232, and one with RS-422/485 levels. The presence of the board eliminates the need for several components and reduces the complexity of the logic required for the operation of our system. Nowadays powerful computer technology allows the development of very simple circuits to accomplish relatively complicated operations. A simple design is essential to reliability in so far as by reducing the number of components needed, the probability of system failure is drastically lowered. The processor board both controls and supervises the activity of three major operations (Fig. 1). First, the input-ouput board is responsible for feeding the necessary voltages to the pulse width modulator (PWM) and motor combination through its digital to analog converters. It also polls the speed of the motors at each sampling time through the optical shaft encoders and the analog to digital converters. Finally, the board processes the joystick signals to extract the desired user speed and direction. Second, the control board processes the strain gage signals [3] and classifies the weight of the user in one of four groups. The adaptive aspect of the controller is provided by the strain gages which are placed under the user seat and thus gives the processor an indication of the user weight. The weight is subsequently classified in one of four predetermined user weight groups and one of four control equations is consequently used in determining the actuating voltages. The third and last component is the two quadrant PWM [3].

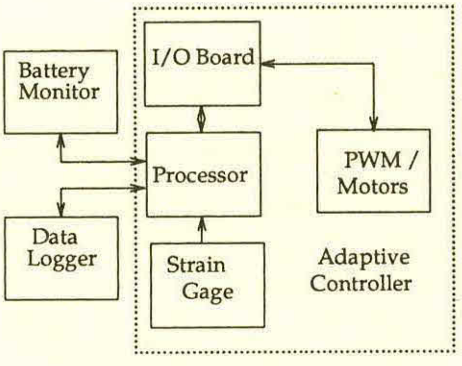

Fig 1: Microprocessor based control system

Communication between the processor board and the host computer is provided by a powerful C-THRU-ROM package which allows remote monitoring and debugging in C.

III- Extended System features

Included in the new implementation are several features introduced to further insure safe operation of the vehicule. One such feature is a mechanical brake that is triggered by the microprocessor when certain perilous situations are encountered such as the chair going out of control in a down slope. Another example of such situations is the common occurence of the wheelchair being stuck against a curb, resulting in the accumulation of the error integral term. Along with the risk of damaging the motors, the user could very well be in danger if the wheelchair suddenly broke free. The processor would check the error integral term and decide to apply the brakes and shut off the motors if the term goes over a certain limit. Also in an effort to rid the wheelchair of the easily worn potentiometer based elements, an optical joystick is being introduced, thus improving reliability [6]. Other additions include the installation of a Data Logging System [4] which automatically records various parameter of wheelchair activity such as time in use or time in motion. Finally a battery monitor [5] is added to the system to give the user an indication of how much power is left in the battery, at all times.

IV- Conclusions

The control system package discussed here,including the new additions endows the Wheelchair with a highly reliable and efficient environment. The design is extremely flexible and insures stability and optimal performance of the vehicule under all possible conditions.

Acknowledgements

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DEVELOPMENT OF A SERIAL AUXILIARY CONTROL INTERFACE FOR POWERED WHEELCHAIRS

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ABSTRACT

The Trace Center has been working with interested manufacturers of communication aids and wheelchairs, in an effort to develop a standard interface for the control of powered wheelchairs by devices such as communication aids and other microprocessor controlled user input devices. This paper describes past and future efforts toward adoption of this proposal as an ISO Standard and summarizes the current draft standard.

INTRODUCTION

As electronic communication aids and environmental control devices become more and more advanced, their ability to perform more sophisticated functions expands. In fact, many aids are based on portable computer systems with tremendous programmability and control capabilities.

As a result of this increased capability, there is a growing interest in interfacing suitable aids to wheelchairs so that the aid can assume the control functions typically performed by joysticks on powered wheelchairs. This would enable people who currently cannot operate standard wheelchair controls to operate a powered wheelchair. Also, the number of control interfaces a person would require could be reduced.

Today, most wheelchair controls are an integrated part of the total wheelchair system. Furthermore, each manufacturer uses different designs and connectors (if any) for their control interface. Because of this, costly custom adaptations are required to replace the existing control, and completely different modifications must be made for each family of wheelchairs.

To remove this barrier, several interested researchers and manufactures have begun development of a electronic interface standard that would allow communication aids and other intelligent control devices to drive future powered wheelchairs. Wheelchairs implementing this standard would provide an auxiliary serial interface port which would allow control of the chair by other devices having a serial output port.

It is felt that a standard interface would benefit consumers, clinicians, and manufacturers of wheelchairs and communication aids. The consumer would have an expanded selection of components from which to choose. Compatible components would reduce the amount of specialized knowledge required of the clinician and make the assembling of a custom system much easier. The manufacturers would enjoy an expanded market for their wheelchairs and aids, a reduction in the amount of customization that is often required, and lower costs for educating dealers and consumers.

BACKGROUND

Initial efforts to develop a control link began at the 1987 RESNA conference and resulted in a draft document of design specifications. Over the past two years continuing revisions have been made. Copies of the working document have been distributed to interested manufacturers and researches.

In November of 1989, the draft document was presented at a meeting of the ISO Wheelchair Standards Working Group. It was favorably received and continued efforts in this area were encouraged. It was recommended that the proposal be submitted to the USA member organization for consideration so that the document can be formally placed on the ISO Working Group agenda.

At this time, the proposal is being submitted to the ANSI/RESNA Technical Advisory Group for consideration.

TECHNICAL SUMMARY

This is a brief summary of the proposed specifications titled, "Serial Wheelchair Control Interface Standard". Both a Short Version and a Long Version of the proposed standard exist. At this time, only the Short Version is under consideration and review.

Transmission Format

Control signals in an encoded packet are transmitted in RS-232C serial format from the controlling device to the powered wheelchair. Data characters are sent as 10 data bits (1 start bit, 8 data bits, no parity, 1 stop bit). This data is transmitted semi-continuously while a hardware handshaking line is active. Any data received by the wheelchair that contains a transmission error will be ignored along with any additional data until the wheelchair can re-synchronize itself with the beginning of the data packets.

Data Format

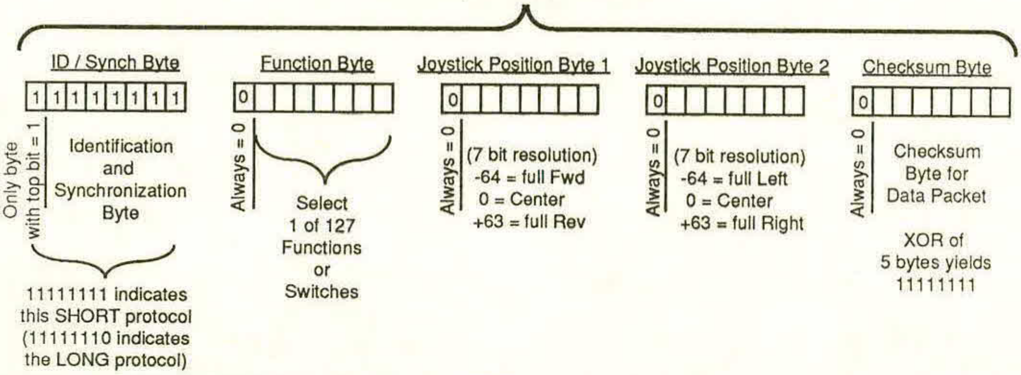
Each packet of information consists of 5 bytes. (See Fig. 1.)

The first byte signals the beginning of the packet and contains an identification number, which can be used to distinguish among different packet formats as well as to allow for future expansion.

The second byte is the Function Byte. It specifies the activation of any one of 127 functions that will be defined in the standard. Examples of these functions are: headlights on, headlights off, recline backrest forward, recline backrest backward.

Figure 1

5 Byte Data Packet



The third and fourth bytes of the packet are the Joystick Position Bytes. These may be used to control wheelchair functions normally controlled with analog transducers. They can be thought of as a digital representation of the analog signal.

The final byte of the packet is the Checksum Byte. It is used to help verify the integrity of the packet as a whole. Any packet received with a checksum error will be ignored.

Data Timing

To insure smooth operation of the wheelchair, the controlling device will be required to transmit data packets on a timely basis. This rate is under review and depends upon the baud rate selected, but some initial guidelines have been proposed. A complete packet should be transmitted to the wheelchair every 40-100ms. If packets are not received by the workshop within a set period of time (e.g., 100-200ms), the wheelchair will stop all activity. This latter requirement will provide automatic fault detection if the control is disabled or disconnected.

Safety Kill Switch

To provide additional safety in the use of this interface, a separately wired, normally closed switch will be required to enable the interface. When this circuit is opened, the wheelchair will immediately cease all movement activity.

Connectors

At this time the use of a 9-pin D connector for handling data transmissions has been proposed. It is widely available and allows for the possible expansion to two-way communication over the interface. The Safety Kill Switch will be connected by a separate line using a standard 3.5mm phone plug.

CONCLUSIONS

The current draft has been reviewed by several individuals and additional revisions are in progress. Initial responses have been favorable and at least three manufacturers have expressed their intention to develop designs based on the standard. A considerable amount of work still remains in developing solid and well designed specifications before the proposal can become an ANSI or ISO Standard. It is essential to its success that people with expertise in this area express their views and provide technical input while the standard is under development.

While this standard will be voluntary, standardization of such control links will help to insure compatibility and assist the user in selecting compatible components. Efforts will continue to insure that these specifications do not restrict creative or innovative design.

Individuals and organizations interested in participating in the development of this standard should contact the Trace Research and Development Center.

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THE NAVCHAIR CONTROL SYSTEM FOR AUTOMATIC ASSISTIVE WHEELCHAIR NAVIGATION

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INTRODUCTION

There are a variety of control systems which permit severely handicapped people to operate a power wheelchair. However, there are still many people who could benefit from powered mobility that are unable to safely and effectively operate any of these systems. Impaired motor, sensory, or perceptual functions which can make it difficult or impossible to operate a power wheelchair include spasticity, tremor, paralysis, weakness, poor vision, visual field neglect, etc. Even wheelchair users with good capabilities for operating a power wheelchair experience collisions with objects in their operating environments (walls, people, etc.).

This paper presents the operational characteristics of an assistive navigation system for wheelchair control named *NavChair*. The NavChair system provides for automatic obstacle avoidance to greatly reduce or eliminate the possibility of collisions for a wheelchair user and wall following capabilities for improved tracking. The goal of this system is to provide improved mobility and safety for people who have impairments which limit their ability to operate a power wheelchair.

METHODS

The NavChair system is based on new mobile robot navigation technology (1). A key advance incorporated into this technology is that the robot does not stop in the autonomous process of avoiding obstacles. Furthermore, speed is only marginally diminished during most avoidance maneuvers.

Obstacle avoidance methods are based on a newly developed technique entitled the "vector field histogram" (VFH) algorithm (1). The VFH method uses a two dimensional Cartesian *histogram grid* for representation of obstacles. Each grid cell contains a time dependent probability that the cell is occupied. These probabilities are continually updated based on range data obtained from ultrasonic sensors. Data from the histogram grid is reduced in two stages. First, the grid is reduced to a one dimensional polar obstacle density histogram centered at the robot's current location. Then, a suitable direction with low obstacle density is chosen in order to move as close as possible to the prescribed direction.

The VFH method allows simultaneous sensing of the environment and control of robot motion, with each newly acquired data point from the sensors immediately affecting robot steering and speed. The VFH method has been found to be effective in compensating for the shortcomings of ultrasonic sensors especially when used in combination with custom developed sampling routines which help eliminate sensor cross talk problems.

A new type of mobile robot operation which has been developed and is the direct basis for the NavChair system is *Tele-autonomous* control. With this method, the mobile robot assumes responsibility for its own protection from collisions (using the algorithms described above), while concurrently following a remote operator's instructions. This approach combines the two traditional modes of control for mobile robots, namely: (a) tele-operated mode, in which an operator has full control over the robot's motions and (b) fully autonomous mode, without direct human interference. Tele-autonomous control was originally designed to operate with robot sensor feedback provided to a remote operator. However, feedback is not required for applications such as the NavChair system where the operator is actually riding on or in direct visual contact with the vehicle under control.

OPERATION

NavChair is an "assistive" control system which combines with an operator's control inputs to improve tracking and provide automatic obstacle avoidance. It can be integrated with standard power wheelchair controls such as a joystick or switch inputs as well as any other type of control scheme (head positioning, voice command, etc.). The NavChair system integrates sensor data into the control scheme and includes algorithms for both obstacle avoidance and wall following. It utilizes a set of ultrasonic transducers placed around a wheelchair in order to sense obstacles in its environment while simultaneously providing input to the motion control algorithms.

Under the standard mode of NavChair operation, a wheelchair (or other vehicle) follows the general direction prescribed by the operator. However, if the wheelchair/vehicle encounters an obstacle, it autonomously avoids collision with that obstacle, trying to match the prescribed direction as well as possible. As soon as the path is clear again, the wheelchair/vehicle resumes motion in the prescribed direction. With this integral self-protection mechanism, wheelchairs or other vehicles can be steered at high speeds and in cluttered environments without fear of collisions.

Most obstacle avoidance methods usually bring a wheelchair/vehicle to a stop when obstacles or potential collisions are identified and then rely totally on the operator to steer around the obstacle. Even in the most sophisticated systems obstacle avoidance requires substantial slowing of a vehicle. In contrast, the NavChair has the ability to automatically steer around obstacles with only a marginal decrease of speed in most situations.

A second mode of operation under development for the NavChair system is "wall following". In this mode the wheelchair travels parallel to a wall as long as some degree of forward motion is signaled from the user. Control commands to steer the wheelchair away from or towards the wall are ignored even if they can be safely performed without the possibility of a collision. Obstacle avoidance remains active during wall following. Manual methods under consideration for switching between normal mode and wall following mode include a separate switch or a coded sequence of wheelchair control inputs (i.e. directing the chair at greater than 90° away from the wall in order to leave wall following mode). Automatic switching between modes is also under consideration.

A third potential mode of operation is possible for training prospective wheelchair operators using the obstacle avoidance algorithms of the NavChair control system. In this mode the NavChair routines would not exhibit any active control over the wheelchair drive system but rather selectively filter out any wheelchair control signals from the user which would lead to a collision. Thus, in a training environment, a user could safely attempt to operate a wheelchair but would not be able to move in the indicated direction unless it was safe to do so. This type of feedback system provides an ideal environment for training individuals with marginal capabilities for wheelchair control.

PROGRESS TO DATE

The NavChair control system has been prototyped using a Cybermation K2A mobile robot platform which has a maximum travel speed of 0.78 m/sec and weighs approximately 125 kg in its current configuration. A 3-wheel synchro-drive permits omni-directional steering under the control of an on board Z-80 controller. Custom hardware developed for this system includes a ring of 24 ultrasonic sensors interfaced with a dedicated controller. An 80386 based computer has also been added on board to run the navigation software and direct the motion of the robot.

Initial testing of this system is being performed with a remote operator in direct view of the prototype using a joystick control to drive the robot. Successful trials have been performed in the laboratory through relatively cluttered environments including chairs, desks, tables, and even vertical dowel rods as narrow as 3/4 inch in diameter. The system's ability to avoid moving obstacles has also been demonstrated in preliminarily trials. Trials with an operator riding on the robot are planned in the near future.

The NavChair control system and the user can be viewed as co-dependent components of the wheelchair navigation system. Engineering analysis of this "shared control" aspect of the NavChair system is being performed to further understand and improve its performance (2).

DISCUSSION

The NavChair control system potentially permits individuals with a wide range of motor, sensory, and perceptual difficulties who would normally be unable to operate a power wheelchair to do so. It also can increase the safety of power wheelchair operation for more capable users.

The NavChair system provides the capability to automatically steer around any stationary or moving obstacle occurring in a wheelchair's path while following the user's general direction and speed input to the greatest extent possible. This includes the elimination of the case where a user "cuts a corner" too close and runs into it — a problem even for wheelchair users with good motor control and sensory perception. It also provides the capacity for an operator to travel through narrow passageways, doorways, and tight spaces by the general indication of a forward control command, since the obstacle avoidance routines will keep the wheelchair centered in such situations. Additionally, the wall following mode allows a wheelchair operator to follow a straight path parallel to a wall even though they could not maintain a straight path on their own.

Planned development for the NavChair system calls for the integration of wall following mode including mechanisms for turning this feature on and off. A second NavChair prototype based on a commercial wheelchair base is the next anticipated step, prior to testing in a wide range of environments. Design criteria to be determined during testing include the minimum number and mounting positions of ultrasonic sensors required for acceptable performance.

An extension of the NavChair technology is also under development to allow people with severe visual impairment to operate a power wheelchair in unstructured environments (2). This system incorporates audio feedback to the operator for navigation in combination with the other NavChair system features.

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Remote Training of Mobility Skills in Persons Who are Physically and Developmentally Disabled

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MOBILITY NEEDS FOR ALL

The large majority of mobility research and development carried out so far has focused on children who are physically disabled and developmentally at or near their age levels. Research into the provision of powered mobility to persons who are developmentally delayed consists mostly of case studies (3) that have tenuous generalization value.

That mobility is important for persons who are developmentally delayed is indicated by results reported by Arlene Aveno (1987). She found that ambulation was ranked as the second most needed skill. Furthermore, mobility related activities (e.g. "walk, bike, stroll in wheelchair") ranked third amongst activities most often engaged in.

RATIONALE

The persons for whom this training program was designed are developmentally delayed and unable to independently stop a powered wheelchair or appropriately change direction when necessary. An adult supervised, in-chair, training program for severely developmentally and physically challenged children takes, in our experience, from 6 to 18 months of twice weekly 30 minute training sessions. Such intensive and long term involvement represents a large expenditure of time on the part of staff members and parents or caregivers who would have to travel to a host centre to participate in such an in-chair training procedure.

The training program thus sought to accommodate:

* elementary mobility skills training
* persons who are developmentally delayed
* at home or in school training
* a demographically scattered population

TRAINING PROGRAM

The goal of the training program is to teach children to operate one of five switches when a stimulus light beside the switch is turned on. There are maximally five switches: four directional ones (forward, right, left, backward) and one stop switch. "Stop" is trained as an active switch activation.

Five training steps were implemented, one for each of the five switches. Each switch has an electrically powered toy connected to it which can be turned on by the child when the switch is enabled.

The demographic spread of the actual and potential clients of this program necessitated the use of a training program that could be reviewed and upgraded remotely. A modem built into the microcomputer is used to collect data, review progress, and make program upgrades from the host centre.

The hardware configuration and trainer unit build for this training program were described in detail in an earlier presentation (2).

SUBJECTS

Sixteen subjects are participating in this study. Six subjects are female. The mean age of the subjects is 11.5 years with a range of 5 years 1 month to 20 years 6 months. Six subjects live in cities remote from the host centre. Five subjects are trained at home and eleven receive training at school.

PROCEDURE

Each subject is assessed in a powered wheelchair using five flat switches to control the wheelchair movement. The subject's ability to drive the wheelchair is assessed with his/her ability to understand cause and effect and ability to understand when and how to stop and turn the chair.

Each subject is assessed for switch placement. Switches are placed on each subject's tray within their active reach.

The Experimental group (n=8) started training at month 0 while the subjects in the Control group did not start training until month six. Assignment to groups was random with the restriction that the groups be equated for age.

Parents are taught how to connect the equipment and are given a Parent Training Manual and cue cards. Parents are asked to return every three months for the experimental stage of the project, and at six months intervals for the control stage. Program updates are made via modem when (a) the child finishes a training stage and the parents receive the "Graduation" message, and/or (b) when the child has mastered the switches of the current stage.

DATA COLLECTED

Data collected include: (a) computer-based data from the training; (b) standardized ratings provided by the parent or teacher; (c) wheelchair driving assessments (initial, 3 months, 6 months and 12 months); (d) a daily log of all incoming and outgoing calls re: this project including functional breakdowns; (e) comments from parents regarding the training program.

RESULTS

With the exception of six subjects all subjects were on the host centre's active caseload and had been referred for a mobility assessment from 6 to 18 months prior to the start of the study. At the start of the study, even the subjects who were assessed 18 months ago, were still not able to drive a wheelchair.

Outcomes of the study to date are displayed in Table 1. With two subjects withdrawn for medical reasons (surgery), seven out of 14 subjects show improvement in their wheelchair driving performance. If the subjects continue to progress towards behaviour listed in lines 6-8 in the table, it is expected, that by month 12 at least one person will be ready for a prescription and that two will need several weeks of in-chair training before receiving their own chair. Another 3 or 4 will have reached the point of having mastered directional switches and will have learned how and when to stop. This amount of change for subjects who have shown virtually no progression for years is extremely encouraging.

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Table 1 Potential and achieved outcomes over time

		EXPERIMENTAL GROUP (n=8)			CONTROL GROUP (n=8)		
	Assessment Session (Months)	0	3	6	0	6	9
	Performance Level						
1.	Unable to stop and turn on request	5	3	3	5	6	4
2.	Turning on request intermittent (2 out of 5 times)	2			1	1	3
3.	Capable of turning on request	1	1	1	2		
4.	Capable of turning at will		3	1			
5.	Some stopping and turning			1			
6.	Mastered stopping and turning			1			
7.	In-chair training recommended						
8.	Wheelchair prescription indicated						
	Subjects withdrawn		1	1		1	1

DRIVER'S EDUCATION FOR POWER MOBILITY: A COMMUNITY APPROACH

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ABSTRACT

While payment sources have become more reticent in arbitrarily funding highly priced pieces of equipment including power mobility systems, more third party payers are willing to authorize funds for a trial period. This paper describes a community based solution to the documentation required when justifying the utilization of power mobility by persons with disabilities.

BACKGROUND

Obligated to curb escalating health care costs, third party reimbursement sources are becoming more cognizant of the need to determine the potential behind recommendations for the purchase of costly durable medical equipment. Included in this high expense category are seating and mobility systems, particularly the power mobility component.

For persons with severe physical disabilities, often mobility is the only life skill performance area in which any degree of independence is possible. While specialized seating systems are increasingly more easily funded with thorough justification documentation, third party payers often have a discrete set of criteria that must be addressed prior to the approval of the mobility component. Many payment sources have found that funding a trial period for power mobility is in effect a cost savings as only those persons demonstrating the ability to use and care for power mobility receive funding, thus decreasing the numbers of units that gather dust as a result of inappropriate recommendations. In addition a trial period can be designed to provide a functional analysis of some of the reimbursement source assessment components such as cognitive ability, visual acuity, visual perception, and emotional maturity that may otherwise be difficult to determine in a person with severe physical disabilities. To address the information required by funding sources, therapists of a rural special education cooperative developed a set of ordered criteria, "Steps to Power Mobility," for the assessment of power mobility including a trial period of utilization.

STEPS TO POWER MOBILITY

First in the list of steps is establishing the need for a new seating and mobility system including a power component. This need is established by the school therapists, but the feasibility inquiry can originate with anyone: parents, classroom teacher, physician, aide, therapy personnel, student, etc. The funding source is then contacted with the recommendation that a wheelchair assessment be performed. When the payment source prefers the school therapists perform the assessment, written guarantee that the equipment is to be funded by the third party payer and not by the school system must be obtained. The funding source also contacts its vendor of choice to arrange the rental of a power wheelchair and adaptive equipment.

Following assessment for home, school, and transportation accessibility conducted by the school therapists, a team, comprised of the student, parents, therapy personnel, classroom teacher, aide, vendor and funding source, will meet to determine an appropriate seating and mobility system for the trial period. After the team meeting, a prescription, containing the seating and mobility system components and the length of the trial period, is sent to the physician for approval and signature.

When the vendor is ready to deliver the wheelchair used for the trial period, the team is reconvened to concur on necessary modifications and approve the delivered wheelchair. The funded trial period, normally 30 days, sometimes has had authorization to be lengthened to 60 days for persons with severe physical limitations.

POWER MOBILITY DRIVER'S EDUCATION

When the power wheelchair is delivered, the student is issued a Learner's Permit. For any inappropriate behavior while in the wheelchair, the Learner's

Permit may be suspended for a one day period. The permit suspended more than five days will result in the recommendation to discontinue power mobility due to a lack of emotional stability, one of the areas in which the payment sources require documentation. Designed to be competency based, the Driver's Education Program covers seven aspects. Documentation consists of a competency chart upon which each competency is written and performance is recorded for each day. A competency is achieved when the student has performed the specific competency a minimum of three school consecutive days.

The seven competencies, including basic driving, turning, moving around people and obstacles, are: to drive in a hallway for a minimum of 100 feet avoiding contact with the walls; to maneuver through the hallway, avoiding contact with two objects; to turn into and out of the classroom independently; to maneuver around two people in the hallway or classroom; to follow behind two people in the hallway for at least 50 feet; to experience mobility on various unlevel surfaces (ramp, outdoors, elevator); and to exhibit safe performance and repositioning of the control site to continue mobility within 45 seconds after a startle response has been elicited.

MORE STEPS TO POWER MOBILITY

When the trial period has been completed, the same team meets to evaluate the trial period performance and make recommendations for the future use of power mobility. If the trial period has not been successful, the funding source is informed of the results. With a successful completion, the team recommends to the payment source that the power mobility equipment be funded. The new seating and power mobility system is delivered to the school, after the therapists assured the funding source that a maintenance plan has been established between the vendor and the parents. Finally, the student's individualized educational program is amended for the additional goals of power mobility.

CASE STUDIES

G., a 14 year old young man with a diagnosis of cerebral palsy resulting in spastic quadriplegia, is in a combined EMH/THM classroom and has a full time aide. For years his parent has wanted him to utilize power mobility. After a debate among school personnel regarding G.'s capabilities, a 60 day trial period was authorized because of his physical limitations. At the end of the trial period, the reconvened team examined the documentation of the 60 days and determined that power mobility was not an option for G., but that he needed a new seating and manual mobility system.

L. is a 17 year old woman with a diagnosis of cerebral palsy resulting in spastic quadriparesis and athetoid movements. She is in a high school TMH classroom and also has a full time aide. Like G., L.'s home, school, and transportation were accessible to power mobility and a 30 day trial period of the appropriate system was approved. After receiving a certificate of completion for a successful trial period, the team recommended that L. was an appropriate candidate for power mobility and that the equipment be purchased for her.

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ABSTRACT

Developing a production version of a mobility device raises concerns over issues such as economy, safety, serviceability, reliability and fine control of operating functions. This paper describes the development of a mobility device motor controller which attempts to provide solutions to some of these issues.

INTRODUCTION

A highly maneuverable powered vehicle called the "five-wheel unicycle system" has been developed. The device was designed for use by those with a variety of disabilities including muscular dystrophy, multiple sclerosis, spina bifida, paraplegia and cerebral palsy (1). It was intendeded for use by those who find difficulty in walking or standing. The basic design of the five wheel unicycle cocomprises a circular, outer frame which has connected to it at least four stabilizing casters. One of the casters is fixed, acting as a 'rudder' for straight line travel. A turntable is connected to the outer frame by a circular ball bearing race. Centrally attached to the turntable is a motorized driving wheel, motor controller, battery and the seat. To provide steering for the vehicle, a steering hoop is connected to the outer frame by an adjustable vertical bar. The user steers the chair by turning his or her body to the desired direction of travel.

Figure 1 illustrates the original design of the motor controller. The original vehicle design used a fairly conventional pulse width modulator (operating at 850 Hz.) to provide control for the single motor used in the system. A single switch or a variable control was used to control the speed of the motor. There were no provisions for dynamic braking or motor reversal.

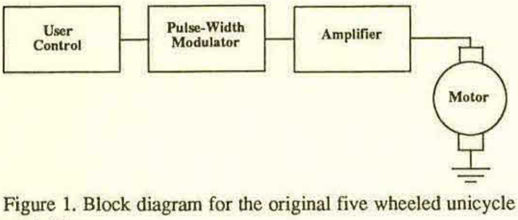

Figure 1. Block diagram for the original five wheeled unicycle controller.

A manufacturer has undertaken the commercialization of the device. All mechanical and electrical aspects of the device were assessed by the manufacturer with a view to minimize costs, increase function, and improve reliability and safety. For the controller, the manufacturer had a number basic requirements, the key ones we have implemented are listed here:

1. The controller should contain a minimum number of components and use commonly available components, but have the capacity for future improvements.
2. The cable size should be 20 gauge or lighter for all the wires going to external controls or displays.
3. The controller board should be capable of (dynamic) braking (under control of a safety switch) and reversing.
4. The controller should incorporate a circuit to monitor the battery charge condition.

In our design, these requirements were used as a starting point. Key concerns in the design of motor controllers for mobility aids are safety and reliability (2). The design presented here discusses the implementation of a motor controller wherein a number of safety and reliability issues are addressed.

METHOD

The motor controller is described below under two sections: hardware and software.

Hardware

The original controller is simple, unfortunately the design provides little flexibility when it comes to improving safety, or increasing user options (as required by the manufacturer). A design based on a microcontroller provides a motor controller design that provides increased functionality with a relatively low increase in cost. The basic design of the motor control board is shown in figure 2.

The microcontroller used in this design is the Motorola MC68705R3. As well as its 24 digital input/output lines, single eight bit timer and two interrupt inputs, the device has a 4 input, 8 bit analog-to-digital convertor. The four analog channels are used to measure the user control setting, the setting of a maximum operating speed potentiometer, the instantaneous current consumed through the motor circuit, and the back electromotive force (BEMF) generated by the motor. The user control is either a variable resistance control or a single pole, single throw, flexible switch, either of which fits on the inside rim of the steering hoop. An arrangement of gel cell batteries provides 24 volts at 19.5 ampere-hours. Power is applied to the motor drive through a relay controlled by the microcontroller. The motor drive is provided by pulse modulation of the battery potential to the motor by way of a power field effect transistor (MOSFET Drive Transistor). A relay controls the reversal of the connection of the motor to the drive circuit. Another MOSFET is used to perform a dynamic braking function, in a pulse width modulation fashion. Display devices for the user's convenience include a light emitting diode which indicates when the power is on and blinks in the case of an error; a miniature speaker that provides auditory alarms for error conditions and a user display consisting of a meter which indicates the battery charge level (using a coulometric technique, during charge and discharge cycles), as well as indicating operating errors. The non-volatile storage device is used for the operation of the battery charge and discharge process.

Software

In order to simplify the development of the software for the controller, its overall functions were divided into 8 task areas. A real-time interrupt is used to switch from one task area to another every 1.25 ms in a cyclic fashion (see task list below).

Task No.	Function
0	Debounce forward/reverse switch, set direction flags, and stop delay.
1	Control braking action to maximum acceleration.
2	Measure user control, ramp speed to present setting or maximum amount.
3	Test safety switch, act if necessary.
4	Read current, accumulate charge.
5	Trigger watchdog timer, check speed limit, test for shorted drive transistor, stall condition, no charging error.
6	Measure maximum speed setting.
7	Control audio output, calculate dynamic braking for user controls.

Each task is completed in less than 1.25 ms. This arrangement allows the software to be simplified by the formation of a number of individual operations that unto themselves are simple, but when all operate together the result appears complex (the total size of the software is less than 2000 bytes).

There are a number of ways to improve the safety and reliability of devices implemented with microcontrollers (3). In the present design, a watchdog timer (4) is used to ensure that the microcontroller is operating. Microcontroller diagnostic programs executed when the device is turned on test the operation of the microcontroller itself, the integrity of some of the internal wiring and other circuit elements. A number of other tests are performed periodically as task 5 of the operating system. The current consumed by the motor is constantly monitored to check for short circuited drive transistors, damaged motor or wiring. The speed is gently ramped up to the user control setting. When a user control is released, the dynamic braking is turned on. The dynamic braking deceleration rate is limited by adjusting the pulse width modulation of the braking FET in accordance with the amount of current generated by the braking action.

DISCUSSION AND CONCLUSIONS

When developing any sort of consumer device, its safety and reliability of operation often are overlooked until later in the design cycle. Since safety and reliability are vital issues in the design of mobility deveices, it is important therefore to build in facilities needed for solving problems in these areas. One approach is to use standard techniques both in hardware and software. Using a watchdog timer, providing circuitry that can be used to test system integrity and providing user feedback devices improves overall confidence in operation. Use of a real-time executive operating system helps organize functions, thus simplifying the overall system design and allowing segregation of safety functions.

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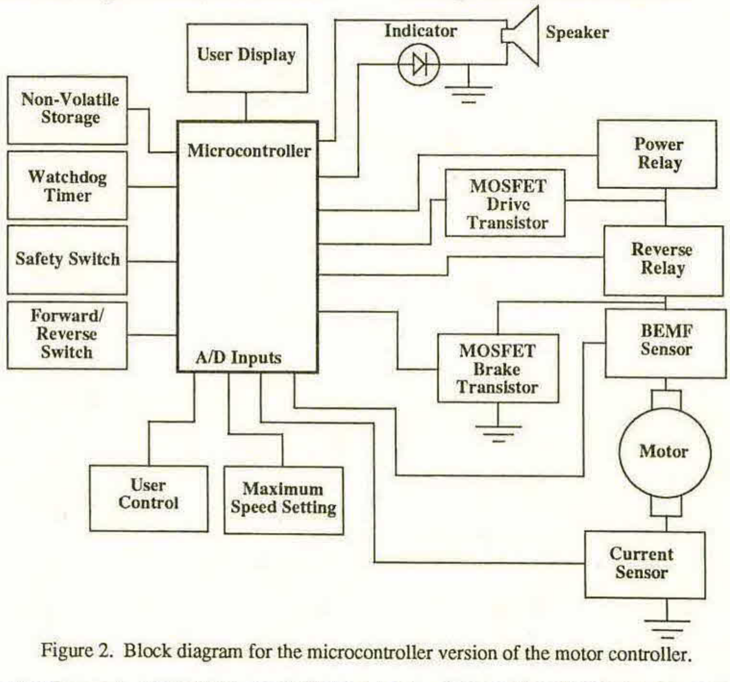

Figure 2. Block diagram for the microcontroller version of the motor controller.

Applications of Force Sensitive Resistors

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ABSTRACT

The Interlink Force Sensing Resistor is a versatile sensor which can, with appropriate instrumentation, be used in a variety of rehabilitation devices for both diagnostic and therapeutic applications. Prior applications have been reported for dynamic pressure measurements under the foot. This paper presents three new applications; a child size finger and hand exercise system with user feedback, a variable pressure general purpose switch, and a direct reading spot meter for measuring contact pressure.

INTRODUCTION

There are many opportunities in the design of rehabilitation devices to incorporate the ability to easily measure and display applied force. Until recently, meeting these opportunities has been limited by the lack of a suitable sensing technology. The Interlink Force Sensing Resistor (FSR) now offers inexpensive, low profile, off-the-shelf sensing components in a variety of configurations (1). These components allow the rehabilitation engineer or technologist to easily meet applications in which force measurement is either essential or useful. Prior applications by other investigators have included dynamic pressure measurements under the foot (2). In this paper three new applications are reported which are: 1. An adjustable hand and finger exercise system for children, 2. A variable pressure general purpose switch, and 3. A direct reading spot meter for measuring interfacial contact pressure.

MATERIALS

The basic component in each application is one of the off-the-shelf configurations of the Interlink FSR device. These devices can be obtained in an applications kit which contains sensors in a variety of sizes and shapes, as well as useful application notes. The sensors are electromechanical thick film devices which resemble membrane switches, but exhibit an electrical resistance which decreases as force is applied perpendicular to the surface. The sensors are less than 0.05 inches thick with an area ranging from 0.2 square inches to as large as 24x24 inches. Typical shapes are square, rectangular and circular. In addition to low cost and ready availability, these devices are not electronically intensive and extensive expertise is not required to produce a device.

FINGER/HAND EXERCISE DEVICE

The design goal for this application was a device in which a child could apply finger pressure and receive a visual and auditory feedback when a desired level of force was achieved. The resulting design consists of an 8 inch long tube with recessed ends into which the child can insert one finger from each hand. At the bottom of the recess on one end is a circular FSR which is used to sense the applied force. The FSR is covered with a thin layer of foam as is the bottom of the inactive recess. This cushions the finger tips as force is applied. The tube contains blinking LEDs along its surface which flash when the desired force level is reached. Inserts are also provided which convert the unit from finger to palm operation. One finger/hand use can be obtained by using only the sensing end of the tube, with the other end braced. The tube is attached to the rest of the system with a telephone type coiled wire. Contained within a standard electronics project box is the supporting force sensing circuitry (Figure 1), batteries, and a chime which provides auditory feedback.

A potentiometer on the outside of the box is provided to adjust the force required to initiate the feedback. A prompt button is also provided which allows the therapist to trigger the feedback to reward subthreshhold effort. One advantage of the FSR design for this application is the mechanical as well as the electronic simplicity. The resultant device is being used successfully in an infant development program.

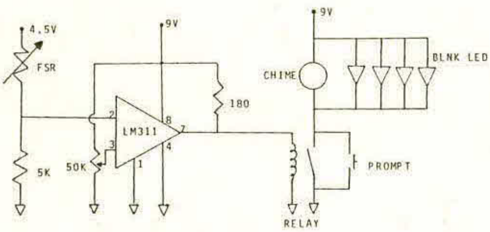

Figure 1. Circuit Diagram

VARIABLE PRESSURE SWITCH

Essentially the same technology and circuit has been used to design a variable pressure switch. This switch has several applications. One is to mechanically filter out inadvertent switch contact while allowing more deliberate activation. A second is to provide a very low pressure switch when required, and a third is to provide a therapeutic goal of requiring increasing force to effect switch closure. Here a 2 inch by 2 inch FSR is mounted on a project box with a protective cover plate of the same size. Again force to voltage circuitry is used in a comparator mode to initiate closure of the output relay when the required force has been applied. This design can be used with any externally powered output device.

INTERFACIAL SPOT METER

One aspect of the prevention of decubitus ulcers is the measurement of pressure between a support surface and the overlying tissue. Several systems are available ranging from relatively complex systems for measuring large surfaces to pneumatically based spot meters which can be used to make single value static measurements (3). The goal in applying FSR technology to this problem was to produce a direct reading, low cost spot meter. For this purpose an FSR was incorporated in a sensing pad which can be placed at a location of interest. The sensing pad is attached by wire to a hand held box containing the necessary circuitry, batteries, and display. In this case the circuit used provides amplified force to voltage conversion following the Interlink application notes (1). The device is reasonably linear over the range necessary for this application. For greater accuracy with analog output, continuous calibration is provided. Alternatively, for a more accurate digital display, a memory based calibration look up table could be used with more complicated electronic support.

CONCLUSIONS

In each of the applications described here a useful, low cost device has been achieved utilizing the force sensing capability of the Interlink FSR. In addition to being of interest themselves, these devices demonstrate the use of this technology which should find many more worthwhile applications.

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Facilitation of Consumer Involvement in P.L. 100-407 Planning Processes

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Abstract -- A state technology planning process emphasizing consumer involvement in the preparation of a grant proposal for P.L. 100-407 is described. This process has implications for other states and regions involved in technology systems planning.

Introduction

Implicit in the language of P.L. 100-407 is the involvement of consumers in the development of state proposals which seek funding under the federal legislation. Though various approaches toward ensuring consumer involvement in the processes of state technology planning have been described (RESNA, 1989), the approach taken by Arkansas has proven to be novel in design, yet highly efficient in practice. This paper describes a model process for optimizing consumer involvement in the processes of P.L. 100-407 grant development which may have important implications for other states desiring to compete for funding under the technology legislation and for state or regional technology planning in general.

Conceptual Model

Prior to the passage of P.L. 100-407, a cooperative grant development effort was initiated by six public and private agencies in Arkansas to address the technology needs of persons with disabilities. Via a 1-year grant through the Arkansas Governor's Developmental Disabilities Planning Council (DDPC) and the University of Arkansas-UAP, the Technology Access for Arkansans (TAARK) Project was funded.

TAARK was designed to: (a) identify the need and quality of technology provisions in Arkansas, (b) disseminate information about appropriate technology and funding, (c) educate Arkansans about technology and advocacy, (d) develop a coordinated state plan for technology , and (e) provide technical assistance to the DDPC.

The TAARK process was based on a systems model developed by the West Virginia Rehabilitation Research and Training Center (1977), referred to as the Institute on Rehabilitation Issues (IRI) process (Havelock ,1974; Human Interaction Research Institute, 1976). The IRI process emphasizes the *collective* input of a wide range of persons from many different programs so as to provide a wide range of perspectives, coupled with the use of study groups to examine issue areas and report to a planning committee. The process is comprised of the following activities: (a) identification of issues/needs; (b) designation of study groups and tasks; (c) study group work and development of a paper in response to group task; (d) review of the document and publication; and (e) dissemination of information evolving from study group document.

Response to Need for Consumer Involvement

The TAARK Coordinated Planning Committee was established in January, 1989. The major thrust of the Coordinated Planning Committee was to develop a state plan for a consumer- responsive statewide system of technology-related assistance, and to develop a grant application in response to P.L. 100-407. Since only 3 of the 15 participants in the first meeting were individuals with disabilities, parents of children with disabilities or their representatives, the participants were requested to nominate at least two individuals with disabilities or parents to serve on the committee. At the next meeting, 46% of the participants were individuals with disabilities, parents of children with disabilities, or their representatives. During this meeting, 6 study groups (Consumer Needs, Information Dissemination and Public Awareness, Legislation and Administrative Policies, National Service Delivery Models, Personnel Issues, and Funding Issues) were organized. Each of these groups met independently from January until March to collect information relevant to their targeted issue area, identify barriers to technology access in Arkansas, and to develop solutions to the barriers. Each study group was charged with the development of a written document identifying problems and suggested solutions to those problems for its respective issue area. The TAARK Project Director was present at each of these study group meetings to facilitate the process and disseminate information regarding the activities and findings of other study groups.

The Coordinated Planning Committee was made up of 48 persons including persons with disabilities, parents, vendors, and representatives of 25 public and private agencies. The committee met 7 times between January and July of 1989. A large part of the early meetings of the Coordinated Planning Committee was devoted to technology awareness and information dissemination activities. National experts were hired to provide information on alternative approaches towards developing a statewide system of technology access, and to facilitate the planning process. In March, a 2-day retreat was held to begin development of the grant application for P.L. 100-407. At the retreat, oral reports were made by each study group.

Written reports were compiled into a document (Parette & VanBiervliet, 1989) that was distributed to all Planning committee members as well as the public on request. Four additional meetings of the Coordinated Planning Committee were held prior to the drafting of the P.L. 100-407 proposal, affording *all* participants with the opportunity to have input.

Throughout the TAARK planning activities, the involvement of individuals with disabilities, their families or representatives, and persons from the private sector were actively encouraged and facilitated. Inherent in the initial grant award was a budgetary allotment for stipends to support involvement of individuals with disabilities and their families at all planning meetings. Stipend support was provided to consumers for child care, attendant services, meals, lodging, and transportation.

Consumer Committee. In May, the Committee designated a group of individuals with disabilities and parents of children with disabilities from the Coordinated Planning Committee to establish priorities for the Arkansas grant application for P.L. 100-407. This aspect of the TAARK planning process represented a unique conceptual divergence from the IRI model, as well as most known state planning models given the primary decision-making roles played by consumers in the design of a state technology plan.

Initial data analyses of an extensive consumer survey (Department of Human Services, Division of Rehabilitation Services, 1989; VanBiervliet & Parette, 1989) were shared with the committee to assist it in its efforts to establish priorities. Following several meetings, the Consumer Committee presented recommendations concerning technology goals and strategies for obtaining the goals to the Coordinated Planning Committee. The recommendations of this committee were presented to the Coordinated Planning Committee. Subsequent meetings focused on strategies to deal with the priorities established by the Consumer Committee. A representative of the Consumer Committee was present at meetings of the grant writing team to ensure that the Consumer Committee's recommendations were contained in the proposal.

Consumer and professional needs survey. Consumer input was also facilitated from across the state via the mechanism of a Consumer Survey designed to assess needs of users, or potential users of technology. The format for the survey instrument included multiple choice questions on specific technology-relevant issues, and open-ended items allowing consumers to express their unique needs and to offer suggestions for those involved in the state planning processes. These suggestions were systematically recorded and compiled for the review of those establishing priorities for the state plan as well as those designing methodologies for the implementation of those priorities. In addition to the Consumer Survey, efforts were made during the information gathering phase of Project TAARK to secure the input of professionals via surveys from across the state regarding their views on technology-related needs.

Interagency coordination. From the outset of the state technology planning activities, interagency participation on a broad level has been encouraged and facilitated. Involvement increased from the six initial members constituting Project TAARK to 55 persons representing 25 public and private groups/ agencies, as well as persons with disabilities and their families. The opportunity for consumers to interact with professionals as a result of TAARK planning activities has been unparalleled in Arkansas.

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A Consumer Responsive Approach in the Application of Rural Rehabilitation Technology

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Introduction:

Testimony given at the "Technology - Related Assistance For Individuals With Disability Act of 1988 Hearings", stated The importance of consumer involvement in the provision of technology - related services was seen as critical by witnesses. In addition, witnesses stated the importance of consumer input throughout the entire process in the delivery of the device/modification. Strategies for involving consumers in the rural service delivery process is very necessary due to unique barriers that individuals face in obtaining assitive technology services. Isolation; lack of financial resources and available services; and too few qualified professionals are among these barriers faced.

This paper will focus on successful methods of involving consumers in all phases of the assistive technology service delivery process. This process includes: assessment of technology needs; development of a solution; and evaluation of the device/modification provided.

Methods:

State wide awareness presentations and media releases resulted in 38 consumers who reside on Iowa farms, being identified as in need of assistive technology services. An Assistive Technology Needs Assessment, Plan, and Evaluation Tool, was developed and administered to 38 consumers. The Needs Assessment included 14 variables related to client demographics; description of problem task; and client's perception on the level of importance that a solution be provided. The Assistive Technology Plan included gathering of data related to 7 variables. These variables included: level of accomodation; client's responsibilities; and counselor's responsibilities. The Evaluation portion of this tool documented data related to 12 variables including: solution provided; nature of instruction given; cost of the solution; who paid for the solution; volunteers and consumers who helped in providing the solution; how well the solution accomplished the problem task; problem that the consumer experienced with the device/modification; frequency of use; why the device/modification is no longer used; quality of the device/modification; and how the device/modification could be improved.

Results:

There were 89 individual problem tasks identified. The nature of these tasks included: 39 vocational tasks; 30 independent living tasks; 18 personal tasks; and 2 therapeutic related tasks. Approximately 50% of the consumers were disabled for less than two years and approximately 40% of the consumers were disabled longer than five years. The average age of the consumer referred for services was 41 years of age. The nature of disabilities included: spinal cord injuries, stroke, Muscular Dystrophy, upper and lower extremity amputations, hearing impairments, visual impairments, low back pain, arthritis, and cerebral palsy. Using a scale of 1 to 5 with 1 being not important and 5 being extremely important, approximately 18% of the problem tasks were rated as important and 72% rated as very important to extremely important that a solution be provided.

There were 42 assitive technology related solutions provided to 26 individuals. The average cost of the solutions were $292 per solution. Approximately 20% of the solutions were paid for by the consumers themselves; 62% of the solutions were donated through the use of a state wide ingenuity network; and 17% were paid for through state agencies. Over 90% of the instructions given on how to use the device were through demonstrations and verbal formats. The total value of all solutions provided was $10,818.

Consumer involvement in locating people, places, and needed materials to provide the necessary solution was documented in 42% of the solutions provided. Preliminary results indicate that assistive technology solutions that required consumer involvement in the service delivery process achieved a higher success rate, after 30 days of use, than those solutions provided without consumer involvement.

Discussion:

Nationally, rehabilitation professionals are trained to provide rehabilitation services to individuals with disabilities. A consumer responsive service delivery approach requires the rehabilitation professional to train the consumer on how they can provide their own solution. Therefore, additional staff training was needed.

Consumers rated how important it was that a solution be provided to overcome a problem task. This level of importance assisted the staff in prioritizing which assistive device/modification needed to be developed first. Preliminary findings demonstrate that consumer involvement relates to the successful use of an assistive device/modification. Furthermore, consumer involvement in the service delivery process has resulted in less staff time required to provide a specific solution.

The next step will be to evaluate all assistive technologies provided, 30 days, 90 days, 6 months, and 12 months after the specific solution has been used. This information will result in better understanding of why devices are used or not used, which in turn will result in selection of devices that are most acceptable to the consumer. In addition, factors that contribute to or detract from successful utilization of assistive technologies by consumers will be identified.

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Computer Controlled Attendant Care Call System

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Abstract

There is a need to make the severely handicapped individual a more independent person. One way of achieving this is through an attendant care call system such that some one can be summoned for assistance when assistance is needed thus eliminating the need for a continuous personal companion. We have designed and built a computer controlled call system which is linked to the apartments via the telephone lines allowing clients to summon assistance through the push of a button. Even though this system has its advantages, it also has its problems in that some people are apprehensive of its usage at first. However, this problem tends to subside with time and practice.

Introduction

There is a current need for Independent Living Centers (ILC) for the severely handicapped individual. However, for a center like this to succeed, many devices are necessary to facilitate the severely handicapped individual. One of the devices which we found necessary is an attendant care call system. Although this device may contradict the idea of independent living, it is a necessary device to create a maximum level of independent living. There were many design possibilities discussed to achieve the call system but we finally decided to design the call system to use a computer as its control center and the standard telephone lines as the communication links. One of the advantages we found by using a computer as the control center is that we are able to store the services provided by the attendants for billing and research purposes.

Background

Currently we are using a ten year old attendant care call system for only twenty-four of one hundred apartments. These twenty-four apartments, which are for the most severely handicapped people, are in one building. The call system requires that wires be run from each apartment to the staff room where the request indicator board is housed. It also requires the staff members to document by hand what services were rendered for each client. Unfortunately, because of the time delay which sometimes occurs between service rendered and service documented, many services were left undocumented.

Another problem with the current system is that the perimeter apartments, which are not physically connected to the main building, are or will be housing severely handicapped individuals. It did not seem feasible to rebuild the current call system to handle the other apartments and run the necessary wiring to connect the apartments to the main control board. On this basis, we decided to redesign the call system such that no wires would be run to each apartment and that expansion would be possible.

We also wanted a means of keeping track of the attendant care rendered without having to write them down. We felt that if the device would keep track of the care rendered, we could use that data for billing and research purposes.

Device Decisions

Immediately we decided that a computer would be the best way to go for the central control unit. The difficult decision was how to link the apartments to the computer and how to display which clients are requesting assistance.

Several devices were considered for communicating between the computer and the apartments. The first one was an off-the-shelf device that used the A.C. power lines for transmitting data. This was thrown out because we could not guarantee that there would not be a transformer between the apartment and the computer. A second possibility was to use radio communication but this did not seem to be economically feasible. The final idea was to use the current telephone system which would require no wiring on our part. This seemed to be the most plausible choice of the three.

The second item we needed to decide on was how to display which apartments are requesting assistance. For this we decided to build our own board and connect it to the computer using the RS-232 serial port.

The computer we require needs to be reliable under 24-hour operation. We also wanted the computer to be compatible with the computers currently in use at the site. Therefore we decided on an AT-compatible commercial grade computer. We also needed to connect the computer to the phone line. Although a modem may seem to be the logical answer, we felt it was necessary for the computer to be able to verbally communicate with the staff when they are calling to enter the services rendered. Consequently, the Black Box DTMF-ASCII convertor (1) with voice synthesis was the best choice. This device allows for touch tone decoding and verbal feedback instructions from the computer.

Design

Since many of the devices are off-the-shelf items, we only needed to design two parts: the display board and the remote control telephone dialer.

We are currently in the process of designing the telephone autodialer which will allow the client to access the call system by remote control. We intend on using a speakerphone that has speed dialing and modify the telephone to call the computer upon signal from the client's remote transmitter and tell the computer which room is requesting assistance through DTMF tones. Since the computer will have a device to decode touch tone messages, we will not need any special devices to transmit the room number information.

The display board, which is already built and installed, was designed to show the layout of the ILC where each apartment has a light emitting diode (LED) to indicate when service is being requested. The board also contains a four digit readout to tell the staff members which apartment has been waiting the longest for attendant care.

The last portion, which is also done, was to write the software to control the system. To do this, Microsoft QuickC 2.0 and Microsoft Macro Assembler 5.1 (2) were used. From these languages, software was written which controls what is shown on the display board, when the phone is answered and the necessary communication for the phone.

Conclusions

We have found from this call system that our biggest hindrance is the training of the staff and clients on the new call system. We noticed that they are apprehensive of the change. We believe that the residents are also partially apprehensive of the new system because the remote control telephone dialer is not yet operational, therefore they must manually press the buttons on their telephones.

We are currently working on finishing the design on the telephone. I feel that once all of the residents are using the new call system, this apprehension will subside.

Acknowledgements

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Funding Assistive Technology Programs and Organizations: Five Case Studies of Success and Innovation

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ABSTRACT

Through this presentation, the authors reveal the results of research completed just one month prior to the RESNA 13th Annual Conference. Responding to an information gap described by numerous service providers interested in developing an assistive technology program within their own organization, the sponsors for this study determined that little systematic research existed which explored "how to" match successful, innovative fund raising with long-term, creative programmatic development. A study was commissioned to explore the role of funding upon assistive technology program development. Five organizations representing a diversity of funding and program models were selected. In-depth interviews were designed to encourage candor and introspection. The results shared in this presentation will also be expanded into report and practical guide to assist administrators and development personnel to emulate elements from these successful models.

BACKGROUND

The authors were commissioned by the sponsoring organizations to respond to an expressed need. How can assistive technology programs be funded on an on-going basis for private non-profit or for-profit organizations?

Currently, some attention is being given to the means by which technology-related assistance can be brought to individuals who need it. A scattering of programs provide the individual with some financial support, advocacy or strategic guidance. Examples include, among others, the National Easter Seal Society's and IBM's collaborative effort to provide computers and assistive peripherals at discount prices. Steven Mendelsohn's book, Financing Adaptive Technology: Alternative Strategies for Blind and Visually Impaired Persons; provides insight into how the system works and strategies for working within it. A number of organizations provide information about assistive technology devices. Databases are almost non-existent for organizations seeking guidance on funding strategies.

Title I of the Technology-Related Assistant for Individuals with Disabilities Act of 1988 has begun to help develop more consumer-responsive service delivery models within the states. However, little systematic guidance is available to organizations which are not state agencies.

The purpose of this project was to identify, study and report upon a variety of private non-profit and for-profit organizations which are successfully providing technology-related assistance to persons with disabilities. In particular, the project sought to reveal and relate how each organization has developed innovative techniques which take advantage of the flexibility provided by some funding sources and overcome the impediments often encountered from others.

The audience for the published study is primarily personnel involved in program administration or fund development. A secondary audience is the person involved in public policy development, where the study can serve as a guide to changes in those policies as opportunities arise.

The project's goals were three-fold:

- identify techniques for locating, obtaining and using funding for assistive technology,
- describe models suggested by the case studies; and
- provide recommendations for replication by other organizations wishing to emulate the success of the case studies.

The project had four stages:

- preparation, review and piloting of protocols for use when reviewing "model" assistive technology programs,
- identification and enlistment of five organizations to be studied,
- on-site information gathering and analysis of funding/programs; and
- preparation of a report on the case studies and a guide for emulation.

Organizations were selected based upon research and consultation with colleagues throughout the country, the sponsoring organizations and an advisory panel. The panel also assisted the authors with development of the study's methodology.

METHODS

The study required that two objectives be met. First, a broad cross-section of funding sources needed to be identified. Second, the funds had to have been creatively employed to establish and maintain programs of excellence in technology-related assistance within private non-profit or for-profit organizations.

The authors recognized that keeping the final report and guide both readable and useful, required brevity. It was considered essential that a broad range of parameters be included, but illustrated through careful selection of sites for study. The inevitable relationship between funding and programmatic development had to be brought out through the study's protocols, interviews and resulting report. It was the authors' intent to dig below the surface facts and figures regarding an organization's funding and program structure, to uncover the underlying philosophy and attitudes which characterized each of them.

It was decided to conduct in-person interviews at each site. A variety of personnel would be interviewed and tape recorded. Efforts were made to include the top administrator of each organization, where appropriate, program administrators and line staff.

Prior to each visit, printed information about each organization was gathered to help familiarize the authors with the organization's administrative structure, assistive technology service programs, annual financial data, etc. In turn, interviewees were provided with a copy of the interview protocol together with an introduction designed to familiarize them with the interview's goals and process. At all times, it was the objective of the study to encourage candor and introspection.

The protocol was always addressed to "you", the person being interviewed. It consisted of open-ended questions contained in nine sections. The questions were listed on the left side of the page. On the right were occasional illustrative, usually opposing, examples of the points the interviewee might wish to consider during the interview. To every extent possible, interviewees were not "led" through their answers. Followup discussion was always encouraged.

The nine sections covered in the interview protocol were:

- your personal perspective
- structure of your organization
- origins and evolution of your assistive technology program
- current program activities
- technology program funding
- impact of funding upon the technology program
- fund raising
- program effectiveness
- your recommendations

It was determined that five case studies, carefully selected, could provide illustrative examples of innovations in funding and programmatic excellence. Organizations were selected upon the basis of a balance between:

- populations served (cross-disability, disability specific, etc.)
- organizational structure (private agency, hospital, university, independent living center, etc.)
- program services (direct client, advocacy, information dissemination, etc.)
- funding sources (governmental, private, fee for service, etc.)
- geographical distribution (East, Midwest, West, etc.)

RESULTS AND DISCUSSION

At the time of submission for peer review by RESNA conference personnel, the five organizations were being contacted and on-site visits arranged. Therefore, the authors' presentation at the conference will be the first opportunity there is to disclose their findings, prior to publication of the report and guide.

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Survey of Need for Rehabilitation Aids in Hong Kong

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Introduction

In Hong Kong, a newly industrialised territory with a rapidly expanding economy, the vast majority of technical aids and rehabilitation equipment is imported. Considerable dissatisfaction has been voiced by the users of such equipment and by professional care givers, particularly in relation to the cost and field support of such equipment and its appropriateness to use by Hong Kong people.

One result is that local design and manufacture of aids is being encouraged and a survey has recently been conducted to identify the areas of greatest need and thus to establish priorities.

Background

In seeking to establish a rehabilitation engineering centre (REC) to promote and coordinate activities in Hong Kong a working party was formed from concerned professional carers, educators and those involved in producing local aids. A quantification of need was considered essential if Government was to be persuaded to establish and support such a centre. In the event the Centre was inaugurated in 1987 following a generous private donation, and the momentum of the original working party was preserved in the guise of an advisory group named the Users' Committee of REC. It is through this committee that a survey of need has recently been conducted to help establish priorities.

The survey was planned in 1988 to clarify the nature and scale of need for rehabilitation aids and equipment, to identify new equipment and techniques which could be introduced beneficially in the future and to indicate which areas were in need of research and development.

Method of Survey

As in broadly similar surveys conducted elsewhere. (A Survey of Aids and Equipment for Disabled People in Scotland, 1988) a postal questionnaire was used to elicit a response from professional care-givers and educators actively involved with people in all disability groups. The questionnaire sought information on the needs in the various service units and in the home - the survey was thus entitled "A Survey of the Need for Rehabilitation Aids and Equipment as Perceived by Professionals in the Field".

The questionnaire comprised three parts: I-an itemised list of aids to be categorized in terms of importance, II-a series of open ended questions and III-a service unit data form.

Four versions of part I were produced, each tailored by appropriate professionals to the principal disability groups, taking care also to accommodate the multiple disability groups.

Questionnaires were distributed by the various rehabilitation agencies to their designated respondents who were subsequently invited to attend briefing sessions. These briefings were intended to reduce the incidence of ambiguous interpretation and to anticipate likely anomalies.

Completed questionnaires were subsequently mailed to the REC for processing and the results were accepted by the Users' Committee in January 1990. A report will be published later in the year for general circulation.

Results of Survey

Seven hundred questionnaires were distributed and the average response rate was 62% (40-80% among the disability groups). Thus valid responses were obtained on behalf of 6% of the total population of disabled persons in Hong Kong.

The results of part I of the questionnaire (itemised aids) were analysed to provide a ranking of perceived need by weighting the individual responses to reflect the number of disabled persons represented and the relative importance placed on each item. These weighted values were then ranked within each disability group to yield the following results [most highly ranked items only].

Physically Handicapped
- Mobility aids and seating

Mentally Handicapped Children
- Biofeedback equipment and computers in therapy/training

Mentally Handicapped Adults-
- Biofeedback, communications and safely equipment

[In both the above MH groups ADL ranked highly in the home environment]

Visually Handicapped
- Reading, measuring and guidance aids.

Hearing Impaired
- Alarms and hearing aids.

The open ended questions in part II were structured to identify problems in design, delivery and maintenance of aids and to illicit suggestions on how to improve or extend the provision. The most common responses are presented (the number in brackets is the percentage of total citations in response to each question).

Supply and maintenance problems

- Difficult to repair, inadequate service by supplier (33)
- Lack of centralised comparative, up to date information on imported aids (22)
- Undue delay in supply (17)
- Too expensive (16)
- Inadequate or inappropriate instructions on use/maintenance (10)

Relating to training

- Need training of field staff in use, construction and repair of aids (32)
- Need training of technical and other field staff in use and maintenance of computer and electronic based aids. (18)

As for new aids proposed and research lines suggested

- Biofeeback (various) (27)
- Computer-assisted aids for learning (11)

Conclusions

While the perceived needs for aids among some categories of disability are similar to those in other countries some peculiar requirements have been identified.

Major problems arise in acquiring and maintaining equipment from abroad. By increasing self reliance these problems may be ameliorated but there is no reason for international suppliers to be complacent.

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Utilization of Isokinetic Dynamometry to Compare Concentric and Eccentric Lower Extremity Strength in Multiple Sclerosis and Able-Bodied Individuals.

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Abstract

This project compared isokinetic quadriceps and hamstring strength of 11 multiple sclerosis (MS) and 9 able-bodied (AB) controls using a KIN-COM™ isokinetic dynamometer. Measurements for average peak torque (AVGPKTRQ) and peak torque (PKTRQ) were recorded during concentric (CONC) knee extension (EXT) and flexion (FLX) at 30, 60, 90°/sec and eccentric (ECC) knee FLX at 45, 60, 75°/sec. Peak torque at all speeds during both CONC and ECC were higher for the AB group. A significant ($p.<05$) difference in PKTRQ during CONC knee EXT was observed between the MS and AB groups at 30, 60, and 90°/sec. ECC knee FLX results indicated no significant difference between groups at any speed. Differences between the two muscle actions showed a higher PKTRQ for ECC for both groups, significant only for the MS subjects. The decrease in PKTRQ with an increase in movement velocity was similar for both groups during CONC FLX and EXT, greater for MS subjects. PKTRQ during ECC showed an upward trend with increasing movement velocity. These results suggest that MS may have a more detrimental affect upon CONC than ECC isokinetic strength in the lower extremities.

Introduction

The primary emphasis in most clinical investigations using isokinetic dynamometry has been in measuring muscle contraction during CONC muscle action only. Several studies of MS subjects have agreed that PKTRQ during CONC muscle action is lower for MS individuals than that for AB. [1,2] Other sources have reported increased contraction time during CONC muscle action, [1,3] points of weakness throughout the range of motion (ROM),[1,3] as well as prolonged reciprocal inhibition time.[3] Data concerning the influence of MS upon lower extremity ECC muscle performance are limited and findings appear to indicate a different trend in muscle performance from that seen during CONC muscle actions.[2] The purpose of this research was to compare lower extremity muscle performance during both CONC and ECC muscle actions in persons with MS with that of AB using isokinetic dynamometry.

Methods

Informed consent was obtained from 20 individuals, 9 AB, $\bar{X}$ age=37.4 yr, ht=176.23 cm, wt=76.4 kg and 11 MS, $\bar{X}$ age=39.3 yr, ht=171.3 cm, wt=74.6 kg subjects. MS individuals were given a standard neurological examination, positively diagnosed by an experienced neurologist, and classified 1-4 on the Kurtzke Disability Status Scale.[4] AVGPKTRQ and PKTRQ of isokinetic knee EXT and FLX were measured using a KIN-COM II™ (Chattanooga, TN) isokinetic dynamometer. Two EXT/FLX protocols were used: *CONC/CONC* 30, 60, 90°/sec quadriceps (QUADS) and hamstrings (HAMS) and *CONC/ECC*, 45, 60, 75°/sec QUADS. AVPKTRQ, PKTRQ, angle at peak torque (ANGPKTRQ) were recorded. Analysis of variance and a post hoc Duncan to determine main effects and interactions among group, muscle, contraction type, and velocity of movement, (alpha=.05) was used.

Results

A correlated *t*-test analysis on all variables indicated no significant difference ($p > .05$) between legs. Therefore, all analyses were made using data from the right leg only.

Concentric/Concentric

A significantly higher AVPKTRQ and PKTRQ for the AB group during CONC EXT QUADS was seen at all three speeds. These results are presented in Table 1. The percent difference between groups for AVPKTRQ and PKTRQ ranged from 29-35% and 30-37%, respectively. The ANGPKTRQ was significantly different between groups at 60° and 90°/sec ($p < 0.01$). The magnitude of decline in PKTRQ over the 3 speeds was 11% for the AB subjects and 20% for the MS subjects. CONC FLX HAMS values, presented in Table 1, were not significantly different between groups for either AVPKTRQ or PKTRQ at any speed. The magnitude of decline in CONC FLX HAMS with the increase in velocity was different for the two groups,(AB 6% vs MS 28%). Significant differences during CONC FLX HAMS were observed in ANGPKTRQ at 60° and 90°/sec, represented by a difference of 8 and 10 degrees, respectively.

TABLE 1.
AVGPKTRQ and PKTRQ during CONC FLX HAMS, CONC EXT QUADS and ECC FLX QUADS.

	CONC EXT QUADS					
	MS			AB		
VELOCITY (deg/sec)	30	60	90	30	60	90
AVGPKTRQ (Nm)	112	98	94	158	149	146
PKTRQ (Nm)	40	120	113	200	188	179
	CONC FLX HAMS					
	MS			AB		
AVGPKTRQ (Nm)	49	44	44	63	62	62
PKTRQ (Nm)	63	55	47	82	80	77
	ECC FLX QUADS					
	MS			AB		
VELOCITY (deg/sec)	45	60	75	45	60	75
AVGPKTRQ (Nm)	135	141	145	158	168	170
PKTRQ (Nm)	164	176	172	186	200	206

Concentric/Eccentric

ECC FLX QUADS results are also presented in Table 1. The increase between 45° and 75°/sec for the AB subjects is twice as large (+10%) as that for the MS subjects (+5%). Absolute differences between groups for AVGPKTRQ, PKTRQ, and ANGPKTRQ were not significant at any of the selected speeds. During ECC FLX QUADS, AVGPKTRQ and PKTRQ were higher than that recorded during CONC EXT QUADS at the same velocities. Only the differences between contraction types associated with the MS subjects were significant.

Discussion

The responses observed for the AB subjects are consistent with those reported previously.[5,6] It is presently unknown why muscular strength performance in MS subjects only partially adheres to these behaviors with variations occurring among muscle groups, velocities, and contraction type. The results of this investigation are similar to those previously reported in MS subjects.[1,2,3] Why these muscle groups appear to respond in a presumably "*normal*" manner with respect certain characteristics and "abnormal" in others is not understood. However, it may be helpful to consider the outward manifestations of the disease and analyze how the presence of these factors have been shown to affect muscle performance in general. In patients with MS-type lesions disturbances in the final common pathway output are believed to assume a variety of forms. A decrease in motoneuron firing frequency and a prolonged refractory period are characteristic of CNS lesions.[7] Such transmission abnormalities could account for the lower PKTRQ in MS subjects. Increased agonist/antagonist coactivation with increased velocity of movement during CONC muscle action has been reported previously[8] and may also be responsible for the lower PKTRQ in the MS subjects. This coactivation does not appear to affect ECC muscle action.[8] It has been suggested that two segmental reflex mechanisms are responsible for the improved activation of quadriceps motoneurons during ECC muscle action.[8] In addition to the aforementioned factors, it has been proposed that a lowering in muscle fiber availability may contribute to decreased muscle strength in persons with upper motoneuron lesions.[9] A lower AVGPKTRQ and larger angular displacement would appear to indicate that the MS group are capable of producing less muscular power. For the clinician, these data provide a direction for therapeutic intervention. Determination that the greatest deficit in lower extremity muscle strength is during concentric muscle actions and at high velocities of movement, establishes an area upon which the therapist can place specific emphasis.

Conclusion

The results of this investigation indicate that lower extremity muscles performance is affected by MS differently dependent upon both the type of contraction being performed as well as the velocity of movement. Since most evaluation of motor performance are presently subjective in nature, isokinetic dynamometry offers both an objective means for establishing muscle performance with MS patients baselines as well as providing guidance for prescribing therapeutic intervention.

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POSTURAL CONTROL IN HEALTHY AGING SUBJECTS

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Abstract: Postural control in quiet standing has been evaluated by determining the "center of pressure," (CP) or the excursion of the vertical projection of the center of gravity. Several techniques have been used traditionally to assess differences in the center of pressure between different test conditions (*e.g.*, eyes open *vs.* eyes closed) in a single test subject, or between healthy subjects and patients with neurologic diseases. These methods include computing the mean CP from numerical averages of each successive instantaneous position from the mean position, or the total excursion of the CP in the fore-aft and left-right directions as an accumulated distance between successive instantaneous positions, or the frequency spectrum of the test period. We have recently reported the use of the fractal dimension of the CP as a comparative measure.[1] In the present study, postural control measures are compared in normal adult subjects, healthy aging subjects, and patients with neurologic disease using the fractal dimension of the center of pressure.

Introduction: Deviations of the center of pressure during quiet standing have been characterized for normal adults and in aging.[2] These measurements have been used to assess neurological disorders of the vestibular and cerebellar systems, and lesions of the pyramidal and extrapyramidal tracts. The deviations have been quantified in terms of the area encompassed by the deviations of the center of pressure in the X-Y plane, as well as by spectral methods.

A method of characterizing planar curves which has had considerable success is the determination of the fractal dimension, D, of a curve.[3] In this context, D is a measure of the degree to which a curve fills the available space. D is calculated from the equation $D = \log(n) / [\log(n) + \log(d/L)]$; n is the number of connected line segments comprising the curve, d is the planar diameter of the curve (the largest distance between 2 points), and L is the cumulative length of the curve. A straight line has a dimension of 1; a curve which completely fills the space has a dimension of 2 (the Euclidean dimension). A curve which traces over itself multiple times could exceed 2.

Methods: Data were collected from 79 adult subjects in good general health ranging in age from 22 to 75 years. Subjects were asked to stand quietly on a Kistler force plate for 1 minute with eyes open, followed by 1 minute with eyes closed. The 3 forces and 3 moments were sampled at 100 Hz and the positions of the center of pressure were computed. The middle 20 second period was analyzed for each trial. The frequency spectra of the anterior-posterior and lateral temporal deviations were also computed.

Results: For the 16 young adult subjects, (ages 22-40 years, mean age 28), the mean value of D with eyes open was 2.07 (sd=0.32), and 2.04 (sd=0.31) with eyes closed. These values were significantly different ($p<.01$) from those measured in 63 healthy aging subjects (ages 47-85 years, mean age 68). In these subjects, the measured dimension was 1.87 (sd=0.21) with eyes open and 1.88 (sd=0.18) with eyes closed.

The power spectral density demonstrated the form $1/f^{\alpha}$, which indicates the presence of multiple time scales and is characteristic of fractal processes.[4,5] The slopes of the power spectra ranged from -0.8 to 1.4 in the young adults, and from -1.1 to -1.8 in the healthy aging subjects.

Discussion: In previous studies[1] we have observed significant differences in postural control measures in patients with Alzheimer's disease, particularly those with significant cognitive impairments. In Alzheimer's disease patients with a Mini-Mental Status Exam score of less than 10, the dimension D of the center of pressure was 1.67 with eyes open and 1.85 with eyes closed. In these cases, the slope of the power fit to the power spectral density is -2.5.

These preliminary studies suggest that measurement of the fractal dimension may be a simple and practical method to assess postural control in quiet standing and to characterize disease states in which postural control is impaired.

Acknowledgments: This work has been supported by research funds from VA Rehabilitation R&D.

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Application of Fitts' Law to Arm Movements Aimed at Targets in People with Cerebral Palsy

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Introduction

We have completed a pilot study, the purpose of which was to investigate the applicability of Fitts' Law to aimed arm movements carried out by individuals with cerebral palsy (Bravo, 1989). Fitts (1954) has suggested that the relationship between speed and accuracy of movement is determined by the information conveyed by a movement. Fitts found that a logarithmic relation exists between subjects' average movement times and the ratio of the distance between the targets to the target widths. The relation, is:

$$MT = a + b\text{Log}_2 2(A/W) \qquad [1]$$

where MT is the duration of the movement, A is its amplitude, W is the width of the target, and a and b are empirically fitted coefficients. The quantity $\text{Log}_2 2(A/W)$ is defined as the index of task difficulty (ID), and can be viewed as a measure of the information content of the movement. The slope parameter b was considered by Fitts as the inverse of the motor system information processing rate channel capacity (MPC), in bits per second.

Equation [1], which has become known as Fitts' Law, "appears to hold under a wide variety of circumstances involving different types of aimed movements, body parts, manipulanda, target arrangements, and physical environments ..." (Meyer et al., 1982, p.451). For example, Jagacinski (1980) found the same relation in step tracking of stationary targets using position-controlled or velocity-controlled joysticks. Jagacinski and Monk (1985) reported that Fitts' Law was a good predictor of the speed-accuracy trade-off for two dimensional movements performed with a helmet-mounted sight or with a joystick. Other examples of the application of Fitts' Law include the work of Card, English and Burr (1978) on text selection using CRTs and Card, Moran and Newel (1986) on the location of pocket calculator keys.

Subjects

Twelve subjects were used in the present experiment. They were divided into two groups of six subjects each, a cerebral palsy group (CP) and a motorically normal group (MN). Each group consisted of three males and three females. Each CP subject had a medical diagnosis of CP; they were selected from a local adult program for physically handicapped individuals. The age range was from 23 to 48 years. All of them used wheelchairs for mobility and had sufficient range of motion and control of one upper limb to complete the required movement task. The MN group ranged in age from 24 to 37 years and had no known neurological or motor dysfunction and no observable limitation of movement. All the subjects involved in this study performed the task with the arm of their choice.

Methods

The task consisted of having the subjects rest their hands in a fixed position at a starting point and, upon the onset of a stimulus controlled by the experimenter, move toward a target located at one of four distances to the right or to the left of the starting point. The movement was to be made as quickly as possible. The target widths and distances were varied.

In order to test the applicability of Fitts' Law to single aimed movements performed by people with CP, three temporal parameters were measured: (1) Reaction Time (RT) (the time latency between the onset of a stimulus and the initiation of a movement); (2) Movement Time (MT) (the time between the initiation of the movement and the hit on the target); and (3) Capture Time (CT), (the total time between the stimulus onset and the target hit (RT + MT)). Three switches were used to signal the events involved in determining RT, MT, and CT: (1) rest position of the subject's hand (an infrared emitter-detector pair), (2) detection of a target hit (pressure sensitive switch covered by aluminum plates of different widths), and (3) the tester switch used to activate the onset of the stimulus, and to initiate the time measuring process.

The stimulus provided to the subjects for movement initiation consisted of a version of the single switch computer game "Anti-Aircraft", which is part of the Motor Training Games (Don Johnston Developmental Systems) for Apple II series computers. All the subjects were tested for RT, MT, and CT in a task similar to the one used by Fitts and Peterson (1964). Analyses of variance, linear trend analyses, and least squares regression line fittings were applied to the pooled data for the MN group, and to the data for each subject in the CP group.

Results

Results for the MN group supported the original Fitts' (1954) findings that the RTs are independent of the index of task difficulty (ID), and that ID is a good predictor of the MTs and CTs in tasks involving arm movements aimed at a target, thus validating the experimental design and measuring apparatus used in this study. Results for subjects in the CP group indicated a dependence of RT, MT, and CT latencies on the ID conditions, and a strong linear relationship between mean MTs and CTs, and the ID for each task condition. The linear relationship did not hold for one cerebral palsied subject who exhibited a high level of spasticity in his arm movements. These findings show that Fitts' Law allows one to systematically evaluate and quantify motor performance. A system such as the one used here could be used to quantify one type of motor behavior, e.g., aimed movements with and without a manipulandum. The results also indicate that the motor performance capacity (MPC) is a good predictor of the upper limb motor abilities of subjects in the CP group. This study also showed that data for the CP subjects cannot be pooled, i.e., each subject is unique.

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21.4

ON INSTRUMENTATION AND A PROTOCOL FOR MONITORING THE EFFECTS OF AN ANTERIORLY TIPPED SEAT ON UPPER EXTREMITY FUNCTION

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ABSTRACT
Better functional performance in school by children with cerebral palsy is one of the prime motives behind the study of seating systems which modify or control sitting posture. Other goals include controlling and preventing skeletal deformities, and improving respiratory and metabolic functions. This paper presents an objective technique to assess upper extremity targeting response abilities which has been used in pilot studies of the effects of alternate seating systems on upper extremity function.

INTRODUCTION

Speed and time measures have been used extensively in motor control research to quantify upper limb performance. Choice response time tasks are commonly used to evaluate the efficiency of the motor system because they provide information on both processing of the information (choice) and the ability to plan and perform movement. It was clinically observed that children who improved head position (ie. control of head movement) by means of correct positioning or biofeedback-based training very often exhibited better quality of manual work. Present research is investigating the effects of a 10° forward inclined classroom seat on respiratory function, trunk stability and upper limb targeting ability in normal children, and in children with cerebral palsy. A strategy has been developed which monitors hand movement in response to a stimulus calling for a specific targeting action, and has been tested with seven children.

METHODOLOGY

Subjects

Four children with cerebral palsy between five and eight years of age, and three non-neurologically impaired children between seven and ten years of age participated in this pilot study. The subjects with spastic cerebral palsy were classified as "mild to moderate", were independent sitters on a flat bench with or without hand support, and were able to ambulate with or without mobility aids.

Instrumentation and Protocol

A tracking system which monitors the position of a specific point in three-dimensional space (Sochaniwskyj et al, 1990) was used to monitor the position of the back of a subject's hand during a simple forward reaching task. During the test sessions, the children sat on a specially constructed chair with an adjustable seat base angle and foot rests which were positioned to ensure full contact with the soles of the subjects' feet while maintaining the ankle joints at right angles. An adjustable table was placed directly in front of the child at elbow level, with two targets, 20 cm apart, mounted on the table and aligned in midline with the body. The tracking system was attached to the back of the subject's dominant hand by means of double-sided tape. Cartesian coordinate data regarding the position of the hand were collected at 18.7 Hz by a microcomputer via a multichannel, 12-bit A/D converter.

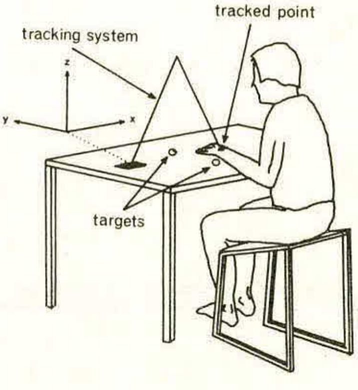

Figure 1. Illustration of the 3D tracking system as it was used to monitor hand movement during targeting tasks.

The test protocol required each subject to be seated on either a (randomly chosen) horizontal (0°) or forward-tilted (10°) seat with the dominant hand placed on the "start" target closest to the subject's body. Upon hearing a verbal cue, the subjects were asked to "hit the other target as quickly as possible". This task was repeated eight times. The seat base angle was then changed and the test repeated another eight times. Measured parameters included average hand velocity and path length measured in both 3D space and in a 2D orthogonal projection onto the tabletop surface. Average velocity was calculated as the path length traversed during the reaction time. Reaction time was defined as the duration between when the instantaneous hand velocity rose above 5 cm/s and then fell below 5 cm/s.

RESULTS

Table 1 summarizes the two-dimensional (tabletop projections) and three-dimensional velocities and path lengths for the two groups of children under the two seat base angle conditions.

Group	Seat Angle	Velocity [cm/s] 2D	Velocity [cm/s] 3D	Path [cm] 2D	Path [cm] 3D
Normal	0°	47.7 (16.5)	52.4 (19.5)	11.1 (6.2)	13.7 (6.7)
	10°	48.7 (13.4)	53.4 (15.5)	11.3 (4.8)	14.4 (4.0)
Cerebral	0°	32.6 (9.8)	36.7 (9.6)	15.1 (6.6)	18.4 (7.9)
Palsy	10°	32.9 (11.1)	38.3 (12.2)	16.2 (8.1)	17.7 (8.8)

Table 1. Summary of means (standard deviations) of the targeting response tests.

Preliminary analysis indicates that there are no significant differences in velocity and path length for either group between the two seat base angle conditions. However, there is a difference between the children with cerebral palsy and the normal children. The children with cerebral palsy appear to move their hands more slowly and traverse a longer path to reach their goal. Figures 2 to 6 illustrate a typical data set from one session with a child with cerebral palsy, showing a comparison of the orthogonal projection of the path onto the tabletop, and the path trajectories for the three separate axes between the two seat angle conditions.

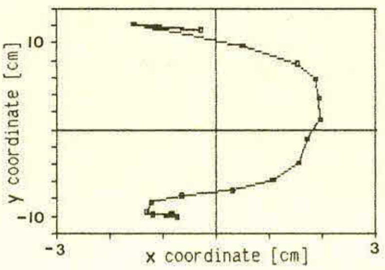

Figure 2. Tabletop path projection (2D) while seated on a 0° seat base.

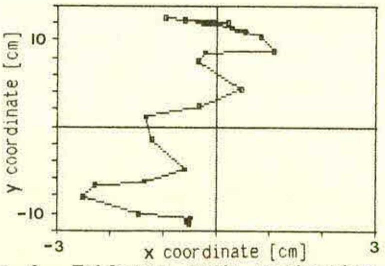

Figure 3. Tabletop path projection (2D) while on a 10° forward-tipped seat base.

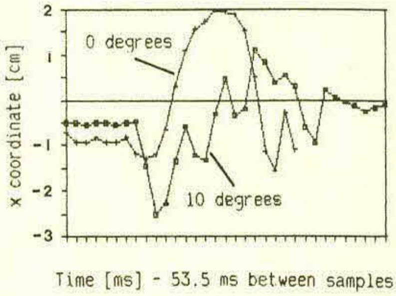

Figure 4. 'x' (lateral) position vs. time.

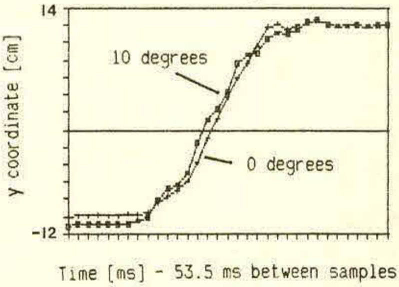

Figure 5. 'y' position vs. time.

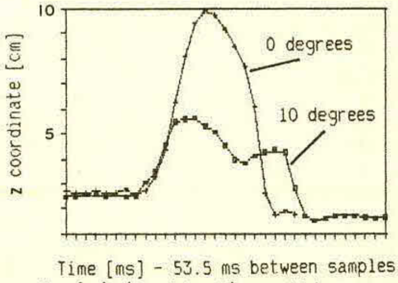

Figure 6. 'z' (vertical) position vs. time.

The number of subjects in this study is being increased and refinements to the tracking system are constantly being implemented. The system is being utilized in a study of the effects of a dorsal-forearm splint on hand function, and in work related to target prediction based on initial hand trajectories for use in gestural communication.

ACKNOWLEDGEMENTS

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21.5

A MINIATURE STEP COUNTER AND SENSOR FOR USE IN CRUTCHES

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ABSTRACT

A miniature step sensor and counter for insertion into standard crutch feet are described. The counter can be removed from the crutch and gives the total number of steps. The design emphasis has been on low cost, small size and ease of use. The hardware design and future applications are discussed along with preliminary results.

INTRODUCTION

The U.K. Department of Health has commissioned an evaluation study of a variety of crutches on the market. The aim of this study is to produce a report for professionals, patients, manufacturers and supplies departments on the advantages and disadvantages of specific design features of crutches and to produce guidelines on crutch prescription. In order to ensure that patients' opinions were based upon reasonable use of the crutch, the Institute was asked to develop a step counter that monitored the activity of the device in question.

Miniature counting units that have been made in the past [1,2] have either necessitated substantial modification to the device, or have been too complex for this application. Studies on the forces applied to crutches [e.g. 3] have used sensors that are overly accurate and expensive for our purposes. An original sensor and counter have therefore been developed.

METHODS

a) Sensor

Fig. 1 shows the sensor, based on an inexpensive piezoelectric crystal found in cheap audio alarms. The crystal is sandwiched between a brass disc and a steel washer, with a hole through the centre to facilitate a flexible connection to the crystal backplate by means of a spring. This ensures that the crystal moves freely, and generates a charge movement on compression. The sheet steel disc transmits the force from the crutch tubing to the crystal via the steel washer. The rubber washer provides electrical insulation and mechanical damping to eliminate high frequency signals from the crystal. The ferrule is supplied to the therapist with the sensor permanently installed instead of the standard ferrule base disc and with an SMC connector ready for connection to the counter

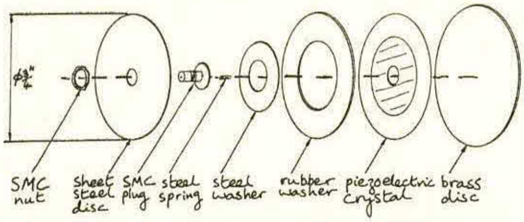

Fig. 1. The step sensor, showing piezoelectric crystal and SMC connector for counter input

unit. Sensors have been constructed to fit 1", 7/8" and 3/4" ferrules. A typical output voltage generated across 1 Megohm is shown in Fig. 2.

Since a piezoelectric crystal gives an output proportional to the rate of change of force applied, the sensor is not affected by steady state forces. Thus the contact pressure on insertion due to the ferrule's grip on the crutch has no effect. A crystal has the added advantage that it requires less movement than a switch on activation.

b) Counter Unit

The counter unit is capable of a total count of over 16,000 steps, and sits at the base of the crutch tube connected to the sensor. The unit is constructed using surface mount technology and has external dimensions 16mm diameter by 86mm length. An integral 3.6V, 15mAh nickel cadmium cell gives over 3 months' continuous operation. The circuit, battery and connectors are embedded in either silicon rubber or epoxy encapsulant.

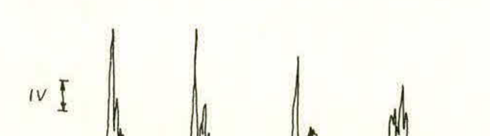

Fig. 2. Typical sensor output into 1 Megohm load

The input comparator (see Fig. 3) has large hysteresis, triggering off and on at 0.8V and 0.1V respectively. The input can be configured to respond to voltage or switch closure signals. A rate limiter is incorporated, so that input signals faster than two steps per second are ignored. CMOS integrated circuits are used throughout. The total count is read out serially through a 4 way connector, which includes a battery recharge pin. The action of charging the battery resets the counter to zero.

c) Display Unit
The mains powered display unit is kept in the rehabilitation laboratory and is used for reading and recharging the counter units after use. The count is displayed in hundreds of steps. The 8 bit total is read in serially and converted to an LCD display drive format (see Fig. 3). While one counter is being read, up to three counters may be recharged simultaneously. The counter may also be read by a computer using a simple interface.

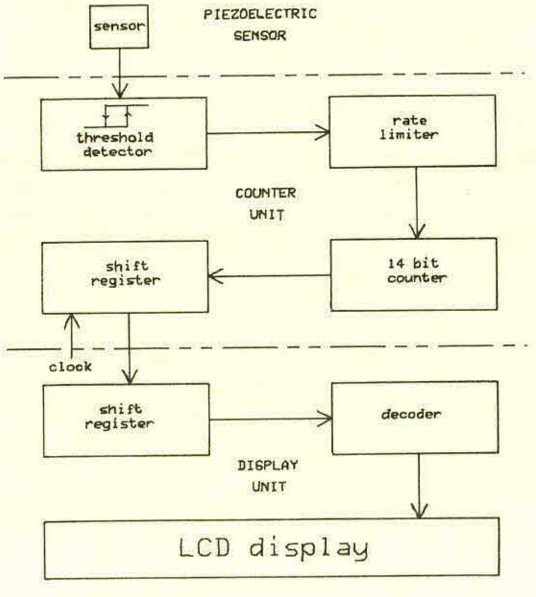

Fig. 3. Diagram of complete step counting system

RESULTS

45 subjects who were currently using crutches (ages 19-76) and who presented with musculo-skeletal disorders of the lower limb participated in the study. Each pair of crutches was tested for three days in several subjects' homes. Data concerning ease of use, comfort and safety was collected using a questionnaire. Results show that handle design is the single most important factor for crutch comfort.

Several problems were encountered during the trial. Some counters were found to have worked loose from the sensor, the ferrule having rotated during use. Some sensors had broken during use, which may make it necessary to embed the sensor in the ferrule rather than pushing it into place. Several counters gave valid readings, and as the above problems are overcome, a reliable indicator of patient compliance will be available.

DISCUSSION

Some users were aware of the counter's presence, whereas some were not. The ethics of concealed monitoring have been considered before [e.g. 2]. With the device described here, the therapist may decide what is appropriate for their client. Thus, if it is felt that funds invested in a device are not being used effectively by an individual, then discreet monitoring is possible.

A smaller counting unit package has been designed so that it may be used in other applications. Possibilities are insertion into shoe heels, wheelchairs, walking frames, seats and so on.

SUMMARY

A miniature step counter has been described along with an accompanying display unit and novel sensor. Several units have been used in a crutch assessment trial, the results from which are being used in further development.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF A PUBLIC DOMAIN, USER ACCESSIBLE, INTER-STATE DIRECTORY/DATABASE FOR ASSISTIVE TECHNOLOGY SERVICE DELIVERY PROGRAMS

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ABSTRACT

With the advent of the Assistive Technology Act and the grants to states, there has been a rapid increase in the interest in service delivery directories. One of the major problems faced by the states, however, is the need to have a database which is flexible enough to meet their particular needs and yet simple enough to operate that it can be readily accessed and used by the wide diversity of people throughout their state. In order to address this problem, a very user-friendly and flexible resource database shell was developed. This database takes advantage of graphics and hypertext strategies to provide a zero-instruction database format. The database looks and acts like a book, except that it is possible to quickly move between sections of the book and to have it automatically create new "chapters" containing just the entries the user is interested in. A first prototype of the system has been completed. After internal testing, it will be released to the pilot states for testing in 1990.

INTRODUCTION

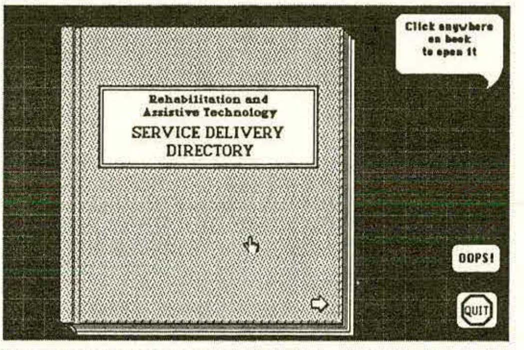
There is a need today for a good mechanism for generating, maintaining and distributing a directory of the various scattered service delivery agencies and programs that handle or specialize in assistive technologies. Although computer-based service delivery and resource databases exist, they typically require a trained operator in order to be used effectively. The operator must not only be an effective clinician with knowledge of the consumers and their problems, but also familiar with computers, the specific computer database system, and, often, Boolean logic search strategies.

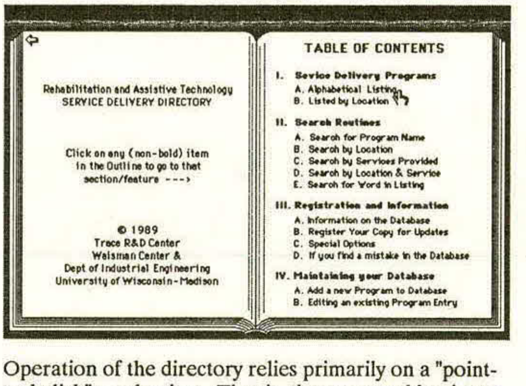
FEATURES OF THE PROPOSED DIRECTORY

The service delivery directory/database shell utilizes many of the same concepts pioneered in Hyper-ABLEDATA. After discussions with states, information brokers, and information consumers, the following criteria were identified as being critical to the development of an effective Service Delivery Directory. The Directory must be:

1) Easy to use;
2) Accessible;
3) Low cost and easy to distribute
4) User customizable; and
5) Easily updated.

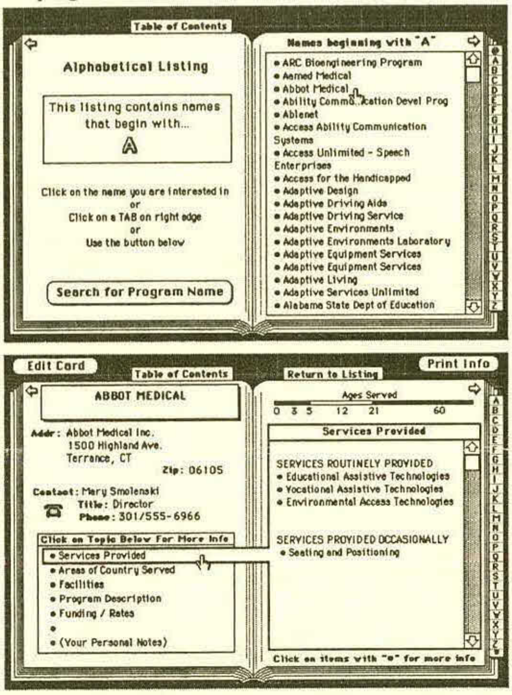
1) Easy to Use
The database was designed to build upon the natural experiences of the user. In order to do this, a "book" motif was used. Other familiar metaphors, such as bookmarks and lettered tabs down the edge of the book (for the alphabetical listing) were also incorporated. In addition, each "page" contains the directions necessary for its use. As a result, no special manuals or training is required for use of the database.





Operation of the directory relies primarily on a "point-and-click" mechanism. That is, the user would point to an item on the computer screen using a mouse or touchscreen. When the user is satisfied that the appropriate item has been pointed to, a click of the mouse button (or removing their finger from the touchscreen) will select that item. (See "Accessibility" for access by users with disabilities.)

In addition to being able to look up listings of service delivery programs arranged alphabetically or by region of the country, it is also possible to do custom searches. Starting with the Table of Contents, the individual would simply click on the type of search they are interested in doing. The database will then show them a map, and ask them to point to the state(s) they are interested in having searched. It then provides a listing of the various types of services or resources covered by the database. The individual would point to or click on the various services in which they are interested. If they wished to limit the search to programs serving a particular age, they could also indicate this. The database will automatically generate a new "chapter" to the book which contains only those entries from the area specified which meet the particular specifications. Initially, these names will be arranged in alphabetical order. The individual has the option, however, of clicking on a button labeled "Ordered by Distance from User." When the individual clicks on this button, the database will ask for the client's ZIP code. It will then order all of the programs in the list (and the "pages" in the "chapter") so that they are ordered by the distance of the program from the client's door.



Other features of the database allow the users to add their own notes to the standard entries, and to add their own entries to the book. Again, everything is done in a paced fashion, with integral instructions, so that special tutorials or manuals should not be needed for any of these standard functions.

2) Accessibility

A key feature in any effective database in assistive technologies is its accessibility to users with disabilities. Unfortunately, many of the same techniques which make a database very user friendly make it very unfriendly to persons with visual or physical disabilities. To address these needs, alternate modes of operating the database are being developed. These include mechanisms for enlarging the text, for allowing complete control through the keyboard (for individuals with movement impairments), the ability to control the program from an external communication aid (for individuals with severe motor impairments), and the ability to operate the database entirely auditorially (for individuals who are blind).

3) Low Cost and Easy to Distribute

In order for the Directory to have widespread use, it must be affordable. Even the $30-40 cost for some books puts them beyond the reach of the average user or advocacy worker, both of whom would find the information very helpful. This problem is amplified by the fact that such resource databases must be continually re-issued every six months or so in order to stay up-to-date. The Service Delivery Directory shell is being made available to the states on a no-cost basis. Individual states can then take the shell and build it into a resource base using information from their individual programs. No dissemination limitations will be placed on the database, so that states are may make as many copies as they wish, and disseminate them within their states (and in other states) freely.

4) User-Customizable

A major problem with traditional databases is the inability of users to add to or customize the database to meet their own needs. Three levels of customizability are planned for the Directory. First, the users are able to add their own notes to any of the entries in the Directory. This is done by simply clicking on the "Your Personal Notes" category and then typing in the desired notes.

Secondly, the users are able to add new service delivery program entries to the Directory. This is particularly useful in rural communities, where the more "established" facilities may be far distant and more unusual local facilities need to be identified. For example, an individual who runs a saw-sharpening and welding service may also do emergency wheelchair repairs. While they would not be listed in the Directory put out by the state, they might be invaluable in a town where the nearest official wheelchair repair facility was hundreds of miles away.

The third mechanism for user customization is the ability to edit existing entries. The database allows the user to edit individual entries, revise incorrect information, or add missing information. In the future, a button in the database will be provided which will automatically make a report of these changes, which can, at the user's option, be mailed back to the State or other central resource directory source.

5) Easily Updated

In order to facilitate the updating process, three mechanisms are built into the database. First, as noted above, it will be easy to generate a report of the edits to the database. Secondly, there is a letter-writing facility built into the database which allows users to quickly and easily type a note back to the source of their Directory. The database automatically creates a self-addressed mailer which includes the note, so that the user need only type a few sentences and apply a stamp in order send information or corrections back to the central source. Third, the database is set up so that it has an auto-update feature. When the user receives an updated copy of the database from the central source, it will be possible for the user to easily transfer all of their individual notes to the new version of the database (rather than losing all of their notes when they started using the new version of the database).

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22.2

VA Rehabilitation Data Base: Theory and Lessons from Clinical Use

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Abstract

The VA Rehabilitation Database is an evolving collection of databases which provide selected data on rehabilitation devices and procedures to participating clinical personnel at 172 VA medical centers and independent outpatient clinics. The purpose of the system is to improve patient outcomes by providing information to clinical decision makers and caregivers. System development is evolutionary with system design based on perspectives of clinical chiefs and practicing clinicians. Experiments with initial databases produced several specific system concepts which define the current system.

To date the system has received limited but growing use in support of clinical decision making, especially in the area of special client needs. Clinicians feel the system has the potential for significantly improving clinical practice.

System Description

The system now consists of five databases: (1) The VA database on CompuServe; (2) TraceBase on-line; (3) Hyper-ABLEDATA; (4) ABLEDATA on-line; and (5) Multi-media Laserdisc System. VA clinical participation in the database program is voluntary and, in general, dependent on clinics possessing or obtaining access to necessary equipment. The VA Rehabilitation Database on CompuServe has been in operation for 3 years, TraceBase on-line for 15 months, and Hyper-ABLEDATA operational at the VA for 4 months. ABLEDATA on-line and Multi-media Laserdisc System are scheduled for implementation in selected clinics in February and March 1990.

An overview and description of the databases are presented in "VA Rehabilitation Database: Overview and Description" (C Moore, S Todd, R Thorp, H Harris 1990).

System Concepts

Interaction with clinical personnel and their supervisors has led to adoption of the following system concepts:

1) **On-site Clinical Location.** Contemporary rehabilitation involves treating the unique needs of each individual. Since individuals are seen at the clinical level, database support must be accessible at the time patients are seen, treatment plans formulated, and devices prescribed. The system needs to be available to all levels of caregivers working with an individual client (e.g., physicians, therapists).

2) **Reliance on Secondary Sources.** The broad scope of rehabilitation, the large number of rehabilitation devices, and the rapid changes in data (e.g., new models, discontinued models, etc.) make primary collection of data by clinical facilities impractical. Thus, the system relies primarily on data sources developed by external organizations (e.g., AbleData, Trace R&D Center) which have a commitment to keep data up to date.

3) **Incremental/Evolutionary Approach.** The system is designed to adapt to the needs of clinical personnel. An incremental/evolutionary approach allows the system to grow in scope, reflect technological advances, and adapt to organizational changes.

The system, comprehensive in concept, has been implemented in parts in order to gain gradual clinical acceptance. Success with early steps provided the basis for system improvements and obtaining the resources necessary for system expansion. The system is dynamic in content and design in order to reflect technological advances, adapt to organizational changes, and increase in sophistication as clinicians gain system experience and adapt clinical practices to new technology.

The initial database on CompuServe was limited to a strictly narrative format. This was because of restricted data storage capacity, the need to transmit data by modem, and the inability of the system to generate computer graphics. While this format was of some value, clinical personnel reported it did not meet their needs in the following ways: (a) Some clinical decisions require data in a graphic format (e.g., frequency response curves for hearing aid prescription); (b) clinicians are reluctant to prescribe devices they have never "seen;" and (c) use of a narrative format did little to overcome "computer anxiety."

4) **Multi-media Format.** To deal with a wide range of issues of clinical applications, a Multi-media database format was selected involving a combination of tactile (touch screen, touch keyboard) audio, graphics, still and motion video. Video Laserdisc allowed color still and motion video with audio. Clinical personnel found this format more useful and appealing than a strictly narrative format. They associated it with commercial television or video recording, and "computer anxiety" seems to have been replaced with a positive attraction. The multi-media format also allows users to approach the system at a level comfortable to their level of computer competency.

5) **Simulation of Device Examination.** Clinicians, while positive about high resolution color images of rehabilitation devices, still reported that such images were not the same as picking up and examining a device and in some cases, such as a hearing aid battery compartment, opening it. A format was developed whereby devices are photographed on all sides (10 degree increments = 36 images) with selected features captured by zoom or enlargement. The computer program was written so that by touching a left or right cursor or the screen a clinician is able to rotate the device, simulating the experience of picking it up. The zoom feature allows the user to touch a feature and quickly view a "blow up" of that feature (e.g., controls, control settings, battery compartments). Clinicians responded enthusiastically to this treatment and felt it represented a satisfactory substitute for possession of the device prior to prescription if evaluative data on the device and names of colleagues who had used the device could be obtained. We hypothesize that there are at least four levels of awareness/information a clinician must reach prior to prescribing a device: (a) awareness of the

existence of the device; (b) a sense of familiarity with a device; (c) data on device characteristics allowing a proper match to patient needs; (d) evaluative information--test results and/or a positive experience by a respected colleague.

6) **Data Standards.** Support of clinical decisions requires that the database function in the context of the practical realities of ongoing clinical practice. In general, many clinicians have dealt with the scarcity of information by developing familiarity with a few devices and "sticking with these devices." Thus, information on new devices has in the past been seen as irrelevant and if unreliable a threat to comfortably established patterns of practice "which work." Clinical personnel do realize that information, if of adequate quality, could open their horizons to new devices. Thus, they tend to approach the VA Rehabilitation Database with significant interest. Their initial use of the database is exploratory to see if the system meets certain intuitive data standards. Stated standards include comprehensiveness, adequacy, currency, and accuracy. Comprehensiveness expresses their desire to see if use of the database would aid in the selection of the best device available (comprehensiveness seems to be explored by search for devices they have heard of but are not familiar with in depth). Adequacy refers to the desire to obtain information pertinent to tailoring device selection to patient needs. Currency refers to practical considerations such as price and coverage of the latest model commercially available. Accuracy refers to the correctness of data presented (currency and accuracy tend to be evaluated through study of information presented on a device with which the clinician is familiar).

Experience suggests that clinicians will reject the entire database as a tool if it fails to meet these intuitively defined standards. Further research is needed to define the range of standards acceptable for clinical use. Existing databases (e.g., AbleData) in general do not meet such standards (and were not intended to--rather they serve as a valuable reference resource). Thus, the VA Rehabilitation Database has followed the policy of obtaining critical comments from clinical users and augmenting data content through primary collection of missing data. Ideally, the quality of data available from secondary sources will increase over time. Experiences with this and other databases provide valuable sources of feedback to sponsors of existing databases.

7) **User-Friendliness.** Clinician comments on user friendliness fall into two categories: ease of operation (covered above under Multi-media) and data indexing/search. Clinicians experience difficulty in searching existing databases because of lack of familiarity with key word indexing. Few users have been sufficiently motivated to master existing indexing structures. Thus clinical use tends to be limited to retrieval of data on single devices restricted by device name or manufacturer name. Discussions are underway with faculty at George Mason University who are working on an expert system front end to aid user access to AbleData. System speed is also important and is discussed below.

8) **Congruence with Clinical Routine.** Clinical personnel are willing to expend considerable time and effort in collection of additional data if they feel with some confidence that such effort would improve service to clients. Thus, since existing databases have limitations in the area of data quality and friendliness, the databases tend to be used most for clients with special needs. Traditional information sources do not typically present sufficiently detailed information to support selection from a set of similar devices (e.g., weight, durability of energy-storing prosthetic feet). Use in the clinical decisions which are comfortably handled with traditional methods and prescription habits require that the database be usable within the time usually allocated for device selection and prescription. In "routine" prescriptions the time available often falls in the range of 30 seconds to 5 minutes (exclusive of documentation, forms completion). This almost mandates location of the database at the central clinical desk or work area. Clinical decision timeframes require a user-friendly front end, rapid computer search and retrieval, and a system which is in constant operation.

9) **Consumer Access.** Many clinicians are encouraging the distribution of selected database information to consumers in the clinical setting. Types and uses of such data fall into three categories: (a) overall orientation of client to nature and consequences of disability; (b) background to facilitate clinician-client communication; (c) data to support participation in the process.

Results

The overall system has been accepted on a pilot basis and has received limited but growing clinical use. All users feel that significant improvements in the databases will be necessary to achieve their full potential and widespread regular use. Major commitments of resources for equipment, software, data collection, and training will await the results of pilot testing. It is expected that positive pilot tests will eventually lead not only to better clinical outcomes but also to basic changes in clinical practice.

Expected benefits from the system are seen as: (a) expanding the range of devices considered, resulting in a higher quality match between client needs and available technology; (b) increased sophistication in use of devices already well known and used; (c) client orientation; (d) reduced cost (e.g., use of less expensive devices that will do just as good a job for an individual client); and (e) an effective supplement to existing methods of clinician training.

Acknowledgements

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22.3

DEVELOPMENT OF AN ASSISTIVE TECHNOLOGY INFORMATION AND REFERRAL SERVICE IN SOUTH CAROLINA

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INTRODUCTION

The lack of coordinated, consumer responsive information resources on assistive technology and related services is often identified as a key factor in the under-utilization of assistive aids and devices by persons with disabilities. Recent federal efforts, including the Technology-Related Assistance for Individuals with Disabilities Act of 1988, have begun to address this critical need in service delivery. However, for the majority of states not yet receiving assistance under this new legislation, existing resources must be used to begin providing information and referral (I&R) services. One example of such a service is the Technology Information Network being developed in New York State (Mann and Lane, 1989).

Like New York, a multi-level information network is currently being implemented in South Carolina (Trachtman, 1989). When fully operational, this network will consist of a centralized information resource center on assistive technology, a consumer responsive I&R service accessible throughout the state, and a statewide network of specialists who are trained to help match individual's needs with available technology resources. This paper describes the development and implementation of the second component of the South Carolina network; a toll-free, computerized I&R system for providing information on assistive technology and related services to all persons in the state. This service is called Access Technology.

BACKGROUND

In order to understand how Access Technology functions, it is important to briefly describe the two organizations who are involved in the development of the program. The first organization is the Center for Rehabilitation Technology Services, or CRTS. Part of CRTS' mission is to develop and test innovative models of assistive technology services, including information and data base systems. The second organization is the South Carolina Services Information System, or SCSIS (pronounced ski-sis). SCSIS provides information on services offered by state and other agencies to all South Carolinians with disabilities and the elderly population. SCSIS has been in operation for over seven years and has a computerized data base of over 3000 service providers in the state. Recognizing the need for an assistive technology I&R service, together with the desire not to create new organizations but rather to use existing resources whenever possible, CRTS and SCSIS entered into a cooperative agreement for developing Access Technology.

METHODS

The underlying philosophy of Access Technology is, whenever possible, to match assistive technology with specialized services in the community to help solve the problem of the person with a need. The roles of the two sponsoring organizations are clearly defined as follows:

Role of CRTS

- Be an information resource for SCSIS on assistive technology applications.
- Provide SCSIS with information gathered on existing assistive technology service providers in South Carolina.
- Have staff and other information resources available to help SCSIS counselors respond to referrals on more difficult or technical questions.
- Help develop and implement public information activities promoting Access Technology.
- Provide continued training opportunities for SCSIS staff on applications of assistive technology.

Role of SCSIS

- Use their existing toll-free telephone number as a contact point for all persons in South Carolina with questions on assistive technology and related services.
- Respond to information oriented questions on assistive technology services, referring questions of a more difficult or technical nature to CRTS.
- Provide periodic reports to CRTS documenting technology related referrals.
- Help promote Access Technology through their existing information dissemination channels.

As part of the cooperative agreement, CRTS has prepared a Counselor Handbook describing in detail the procedures for taking a technology-related call, developing search strate-

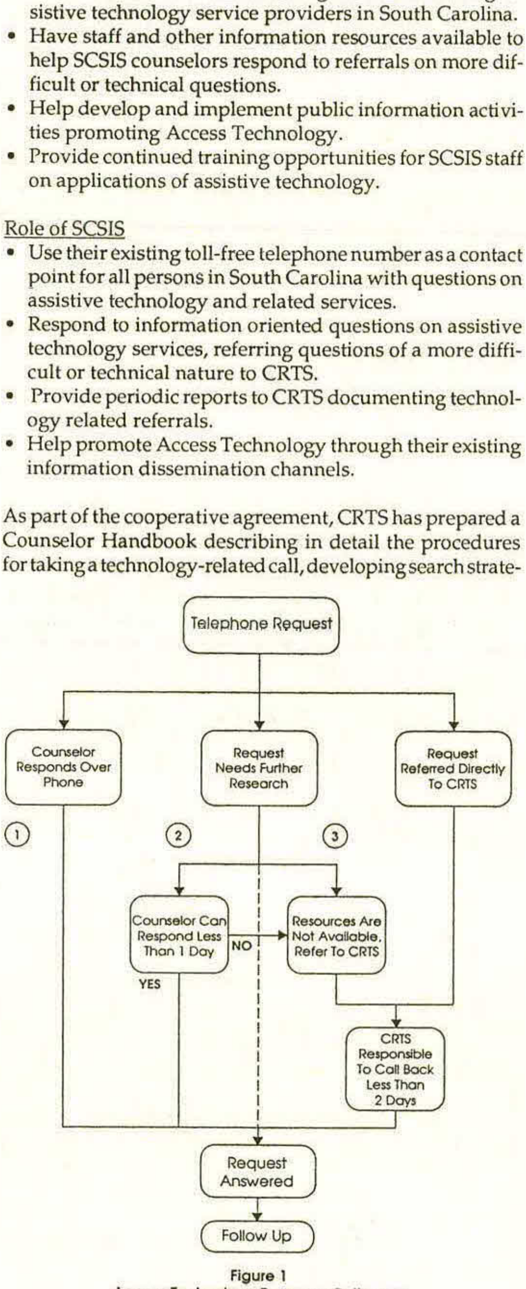

Figure 1
Access Technology Response Pathways

gies to identify available resources, documenting calls, preparing information support packages, and following up on selected calls to the system. Figure 1 shows the three response pathways which are available through Access Technology.

RESULTS

Since going on-line September 1, 1989, very limited public awareness has been done concerning Access Technology. The information below highlights the first four months of project activity:

Total calls: 108
Total referrals: 338
Average age of caller: 48 years

Calls have been received from 28 of the 46 counties in South Carolina. Two-thirds of the calls were from consumers and one-third was from agency staff on behalf of an individual with a disability. Of the total number of calls received by SCSIS during this period, 7 percent were technology related calls.

Sample Service Requests:

Financial assistance for:
accessible fishing pier
computer
elevator in Court House
hearing aid
hospital bed
kitchen/bath modification
prosthesis
wheelchair

Other:
automatic page turner
automobile/van adaptation
baby signaling device for deaf parents
braille books
car seat for child with special needs
closed caption decoder
clothes/shoes for dwarf
computer equipment
driver training
emergency call system
evaluation for augmentative communication
hands-free telephone
phone amplification
phone flasher for the deaf
portable telephone for wheelchair
ramp
talking watch
tape player for blind
TTY
wheelchair cushion

Major Disability Groups:
Aging
ALS
Amputee
Arthritis
Cerebral Palsy
Dwarfism
Head Injury
Hearing Impaired
Mentally Retarded
Multiple Sclerosis
Muscular Dystrophy
Paralysis
Paraplegia
Physically Handicapped
Polio
Quadriplegia
Stroke
Visually Impaired

Each month, the staff of CRTS and SCSIS meet to discuss all technology related calls. Suggestions are given by both staffs as to the appropriateness of the given referrals and suggestions for additional referrals. Recommendations are made as to which calls should be followed up. Staff report the results of the follow-up calls at the next month's meeting. Of the calls for which evaluations have been completed, all callers received information or products as a direct result of contacting Access Technology.

DISCUSSION

Critical elements in the development and implementation of Access Technology have included data collection, training, and marketing. Additional information related to South Carolina service providers (both private and public) specializing in assistive technology is currently being collected by CRTS and will be forwarded to SCSIS to enhance and embellish the Access Technology service. The goal is to gather information on providers who not only supply the technology, but will also assess and evaluate the individual's needs for technology services. Collecting this information is an important, yet difficult aspect of implementing this type of service.

Prior to responding to technology related calls, counselors at SCSIS received training from CRTS on the types and levels of assistive technology, available resources (i.e., directories, catalogues, etc.), and how to query callers. Counselors also participated in several role plays and discussed case examples. Counselors regularly refer to the Handbook developed by CRTS for guidance in responding to calls and to review procedures on completing and documenting calls. While this training has been valuable, the need for ongoing training for staff of both organizations is essential.

Initially, public information about Access Technology was purposefully kept at a minimum in order to determine to what extent available resources could meet the demand for services. After four months of operation, we have found that the number of calls is reasonable compared to the staff available to respond. Marketing efforts are gradually being increased, including direct mailings and press releases. However, careful monitoring will be done to help assure that the quality of services remains high should the number of calls substantially increase.

ACKNOWLEDGEMENTS

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The South Carolina Services Information System is part of the Center for Developmental Disabilities, University of South Carolina School of Medicine and is supported by the State of South Carolina and the South Carolina Developmental Disabilities Council.

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22.4

A public accessible computer-based rehabilitation information service in Hong Kong

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ABSTRACT

A public accessible computer based rehabilitation information service (RIS) is recently established in Hong Kong, a metropolitan city of population six million. Users can search for locally made technical aids, services, as well as current projects. They can also leave and receive messages from each other. An account is given of the purpose of this service and the way the service is implemented.

BACKGROUND

The Jockey Club Rehabilitation Engineering Centre (REC) was set up as a department in the Hong Kong Polytechnic (HKP) in 1987. It has a wide mandate (Evans 1989) and two of the functions are the organization and dissemination of information, and the coordination of rehabilitation engineering efforts. It was thought that a direct, public accessible computer based information service might help to achieve these aims.

The aims of the service are: -

A. to provide the latest information on

   1. mainly locally-made technical aids
   2. current projects on
      - technical aids
      - research and development
   3. services for the disabled

B. to provide a communication channel in the form of electronic mail

About a year was spent on defining the information service in details, developing a classification code, and consultation with other rehabilitation organizations. The system was ready for internal trial at the end of 1989. Early in 1990, the service will be ready for assessment by rehabilitation professionals.

IMPLEMENTATION

To save time and money, it was decided that the facilities and expertise of the Computer Centre in the HKP should be used. The Centre has a dial-up facility with two telephone lines, 2400 baud modems and a cluster of mini-mainframes for academic applications. The RIS was implemented in one of the computers and public access is through the dial-up facility. With the Computer Centre absorbing the cost of software coding and maintenance of existing hardware, the cost of the RIS to users is nil.

Since the focus is on locally produced aids, the maximum capacity of the RIS is set at 5,000 items. Borrowing the number coding method from the Nordic Classification System (3rd ed., Nov. 1986), a 6 digit classification code system was developed for technical aids, services and current projects. Existing classification systems were found to be too comprehensive for the compact RIS.

REC collects and compiles the data. A copy of the compiled data is send to the originator for verification. Only REC can modify data-base information on-line.

Information contained within the RIS is not privileged but to protect RIS data and other data in the computer cluster, a five character password is used to log-on to the computer cluster and a six character password is used to access the RIS. Each user has a unique six character password to facilitate compilation of usage statistics.

The same record structure is used for technical aids, services and current projects. Each record has a 75 character title field, up to six classification code fields, a one digit nature of organization field, and a description field of fifteen lines of 75 characters each. The title and description are limited to about 220 words total so as to ensure a reasonably fast response time for on-line usage but long enough to give the user sufficient information to decide if he wants to obtain more details from the supplier.

The RIS is user friendly with a menu system and simple on screen instructions. A user can either use the menu system to guide him to items of interest or use classification codes for direct searching. The RIS will display the number of items found. The user can then look at the descriptive titles to see if there are any items of interest before using the 'product code' associated with each title to examine the full item description. A simple keyboard operation will then display the address information, if required.

For electronic mail, a message can be up to sixteen lines of 75 characters each. Each message can be addressed to only one other user. The exception is that REC can address a message to all users i.e. broadcasting. This will be useful for announcing matters of general interest such as a lecture on rehabilitation service delivery. A user will automatically be prompted about a new message when he logs-on to the RIS.

Discussion

Provision of a dial-up RIS with an electronic mail feature hopefully will provide the diverse groups of people concerned with the disabled such as occupational therapists, special school teachers, researchers and professional volunteers with up to date information on aids made locally, services available and what is happening in the field. It should also encourage and stimulate co-operation among technical aids producers.

Implementation of the RIS on a mini-mainframe takes advantage of existing resources. The only disadvantage is that the dial-up facility is used by other users of the computer cluster which means RIS users have to compete with a large number of other users. If the RIS is proved to be sufficiently useful, the expertise of the Computer Centre will again be employed to implement the service as a personal computer based, standalone system with a dedicated telephone line to increase accessibility.

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VA Rehabilitation Database-Overview and Description

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Abstract

The VA Rehabilitation Database is a collection of databases which provide information on rehabilitation devices and procedures to clinical personnel at VA medical centers and clinics. This paper discusses the overall concept of the project and its goals. Each component database is described in terms of its data content and the method of implementation. Specifics are given on hardware and software where appropriate.

Definition and Purpose

Surveys conducted by the Dept. of Veterans Affairs (VA) show that clinicians, both within and outside of the VA, are aware of only a fraction of the assistive devices which are available. This is through no fault of the clinicians, but stems from the lack of a system that makes organized information accessible to these professionals. Studies conducted by the Congressional Office of Technology Assessment report that the primary source of information on rehabilitation devices is the device manufacturer--either by sending information to clinicians and their host organizations or through exhibits at professional or trade shows. This process has some limiting consequences. Firms with large or aggressive marketing budgets provide the most information, at the expense of potentially equal or more innovative smaller firms. Clinicians usually have little time and inadequate space to keep files on information about devices. Moreover, information provided by manufacturers varies in terms of format and descriptions. As a result, prescription is often(and understandably) limited to "tried and true" devices.

The VA Rehabilitation Database is defined as a database on rehabilitation devices and procedures organized and disseminated by the Prosthetics R&D Center (PRDC). The target audiences are the VA medical centers and clinics nationwide. The database is intended to provide comprehensive information on all rehabilitation devices. The system also includes additional information that participating clinical service chiefs may designate as useful for their services operational needs (e.g., state-of-the-art summaries, identification of personnel with special knowledge of devices, special product reviews, continuing education).

System Concept

The VA Rehabilitation Database is in the early stages of development and implementation. When completed it will have the following features:

- --Comprehensive computer database on all known rehabilitation devices.
- --Continual updates on devices to keep information provided current.
- --Information provided in a standard format relevant to the clinician's prescription and use decisions.
- --Information provided by clinicians within the VA who have used a specific device with their name and number so they may be contacted.
- --Evaluation, feedback, and cost information.
- --Full color video still pictures of rehabilitation devices.
- --Selected portions of audio for demonstration and clarification of devices and concepts.
- --Full motion video pictures of devices and their uses with actual clients.
- --Computer-based training using interactive video and audio.
- --Interactive video that allows clinicians to quickly and easily select only those portions of the video that are of interest.
- --A system that is user-friendly, operated by touch screen and prompt menus.

The system is being implemented in stages and now consists of five databases: (1) VA Rehabilitation database on CompuServe; (2) TraceBase on-line; (3) Hyper-ABLEDATA; (4) ABLEDATA on-line; (5) Multi-media video laser disc system.

The VA Rehabilitation Database on CompuServe

This database provides selected portions of the Journal of Rehabilitation Research and Development on-line. It is available to users within and outside of the VA system. At present, abstracts of all scientific articles, Calendar of Events, and current Publications of Interest are available. Rehabilitation R&D Progress Reports and a listing of commercially available adult wheelchairs are also on-line. Subscribers to CompuServe may access the database by typing "GO REHAB" (or GO HUD and selecting the "Research and Development" menu option). This is a highly menu driven database and has no search capabilities. However, the menus are logically laid out and they follow the Journal's structure for date, volume and number.

TraceBase on-line

This database contains information provided by the Trace R & D Center and is very similar to the information in their published Resource Books. This particular database will be replaced by ABLEDATA on-line in early 1990. Currently, the database is only available by modem. It is planned that access to the database will be available over the VA packet-switching data network, which would remove the need for a modem by the users. The database has search capabilities allowing users to search for devices by brand name, keyword or manufacturer. The data is maintained on an IBM AT class computer running MUMPS, a multi-user operating system. The database manager is FileManager.

Hyper-ABLEDATA

The Office of Technology Transfer (OTT) is a dissemination point for CO-NET, a cooperative network established to distribute information on assistive technology. One of the prime databases for CO-NET is Hyper-ABLEDATA. This is a Hypercard version of the ABLEDATA database which presently runs exclusively on Apple Macintosh computers. It is hoped that in the near future OTT will be able to handle phone requests for information contained in Hyper-ABLEDATA. Until then use of this database is limited to individuals who can copy the database or use OTT's Macintosh.

ABLEDATA on-line

This database contains information provided by the Adaptive Equipment Center at Newington Children's Hospital. It is a current and up to date version of the ABLEDATA database. This version is accessible by modem and will soon be accessible over the VA data network. The database has search capabilities allowing users to search for devices by brand name, keyword or manufacturer. The users query the database with a screen oriented form. The form unburdens the user from having to type in query commands directly. The database is maintained on an 80386 IBM AT compatible computer running the Xenix operating system. The database manager is Oracle, a relational database management system that incorporates Structured Query Language (SQL).

Multi-media video laser disc system

This database is unique in that it will contain information that has been tailored to individual clinical services. During the development of a services section the service chief and resident experts determine which information is the most relevant. There are three services which will be included in the inital stages. They are:
a) Audiology and Speech Pathology Service; the database is intended to extend the clinicians information on in-the-ear hearing aids. The data will include frequency response curves. Planned for future development is computer assisted selection of in-the-ear hearing aids which will draw on the database of frequency response curves.
b) Spinal Cord Injury Service; the database is intended to present and demonstrate a minimum level of care for selected topics in the management of spinal cord injury patients, such as the prevention and treatment of decubitus ulcers or respiratory care. Training tapes will be edited specifically for interactive video training and reference. The audience will be clinical professionals as well as patients.
c) Prosthetics and Sensory Aids Service; the database is intended to assist clinics in accommodating new devices for prescription. The data content is planned to augment the selection of approved prostheses. This will be in the form of comparative data for selected groups of prostheses (e.g. artificial feet). As an example, the selection of an artificial foot would present data from manufacturers on weight, cost, material, energy storage, etc. This would include video footage, as appropriate, showing important performance differences such as heel strike and toe lift-off.

This database will also include the ABLEDATA database. ABLEDATA will be supplemented by video still images that can provide multiple views and close-ups of devices. There will also be full motion video that illuminates the use and care of particular devices. The system will include audio for demonstration of features and to clarify confusing points about features or use of particular devices. This system uses the IBM Infowindow monitor, a touchscreen monitor designed to work with video laserdisc players and IBM compatible personal computers.

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23.1

SOCKET DESIGN FOR A PROTOTYPE E.P.P. SHOULDER DISARTICULATION PROSTHESIS

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ABSTRACT

Extended physiological proprioceptive (EPP) control in a shoulder disarticulation (SD) prosthesis requires a socket design that provides suspension and stabilization of the prosthesis and permits displacement of the controlling physiological joint—the shoulder—relative to the socket. A SD socket design has been developed which permits relative shoulder elevation and depression. The design has been evaluated in three clinical SD fittings for its application to an EPP-type prosthesis.

INTRODUCTION

Our laboratory has been working toward the design of a shoulder disarticulation prosthesis which utilizes the concept of extended physiological proprioception for control of an electric elbow (1). As described by Simpson (2), an EPP controller links the movement of the most distal intact physiological joint with one or more prosthetic joints such that the proprioceptive senses of the intact joint can be used to determine the position and movement characteristics of the prosthetic joint. In the EPP-SD prosthesis being developed, shoulder elevation and depression control elbow flexion and extension, see Figure 1. The controller itself is a force-actuated position-servo (3), that derives a motor drive signal from the tension in a cable crossing the elbow joint, linking the physiological shoulder with the prosthetic forearm.

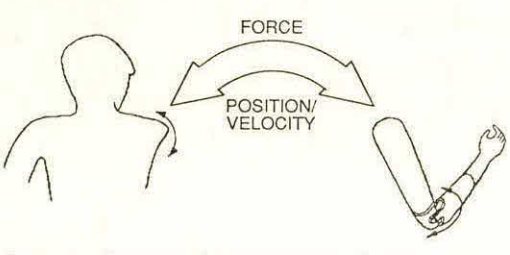

Figure 1. Conceptual arrangement of a one degree-of-freedom EPP controller for a shoulder disarticulation prosthesis.

For the physiological shoulder and prosthetic elbow to move in tandem, the shoulder must be able to displace relative to the socket of the prosthesis. Therefore, the socket must offer minimal obstruction to the movement of the shoulder but continue to support and stabilize the prosthesis.

The socket objectives are achieved through a combination of casting technique, modifications to the plaster model, and iterative modifications to the check socket to produce a shoulder cutout.

METHODS

Casting

The trimlines for the socket essentially extend over the entire region of the rib cage on the amputated side, except for the posterior inferior corner. The weight distribution in an arm prosthesis typically produces a torque which unloads this region. Superiorly, the trimline is placed as close to the neck as comfortable.

Plaster splints are applied and hand molded to conform to the contours of the torso, with special attention to the prevention of lateral gapping below the axilla and anterior-posterior widening of the cast. Care is taken to define the clavicle and the spine and borders of the scapula in the cast.

An anterior-posterior dimension is measured before removal of the cast and is preserved throughout the forming of the plaster model.

Modification of the plaster model

The primary modifications are directed at relieving the clavicle and the spine of the scapula and creating allowance for the angular displacement of these bony structures as the shoulder is elevated and depressed.

Check socket

A Surlyn® check socket is used to verify contact between the torso and the socket over the region of the rib cage and to determine that the bony structures of the shoulder are adequately relieved. Minor gapping is corrected by heating and reshaping the socket.

An initial (conservative) cutout is established through which the shoulder can elevate. Regions where the borders of the cutout obstruct the upward movement of the shoulder are noted and the cutout is enlarged. The extent to which the cutout can be enlarged is guided by considerations for the structural integrity of the socket, the placement of the prosthetic shoulder joint, and, if the subject is bilaterally involved, preservation of biscapular abduction for cable-operation of the contralateral prosthesis.

The socket reliefs and trimlines are modified until the acromioclavicular joint can be displaced vertically one to two inches with respect to the lateral border of the shoulder cutout.

A second plaster model is made from the modified check socket, and a definitive laminated polyester socket is fabricated.

RESULTS / DISCUSSION

This socket design has been evaluated with three subjects who have SD prostheses. These subjects are using shoulder elevation to operate a multi-position harness switch to control an electric-powered component, see Figure 2.

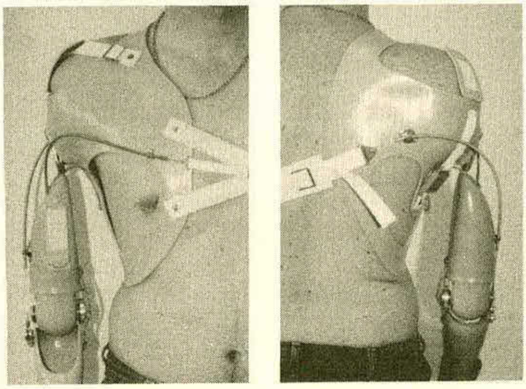

Figure 2. Anterior and posterior views of a shoulder disarticulation socket which permits shoulder displacement for control operation.

Load Bearing and rotational stability
The extent of the socket, over the area of the rib cage, provides adequate surface area to bear the weight (five to seven pounds, including the socket) of the prosthesis with relative comfort. Pressure distribution has been more than sufficient and panels are able to be cut out of the socket anteriorly and posteriorly to provide heat dissipation.

The broad expanse of the socket and the conformation of the socket to the torso also provide good mechanical leverage against external forces that produce torques on the socket. The subjects indicate that use of the prosthesis rarely displaces the socket relative to the shoulder to the extent that the shoulder-operated switch is inappropriately activated.

Freedom of shoulder elevation
The switches used by the three subjects require a maximum 7/32 in. (5.5 mm) displacement. However, as the switch is pulled through its travel, a spring exerts a return force, increasing to 2.5 lb_f (11.1 N) before the switch reaches its mechanical limit. Consequently, the force-coupling of the shoulder to the socket (through the switch mechanism) lifts the socket as the shoulder is raised, thus compromising relative shoulder displacement.

Though the EPP controller also involves force-coupling between the shoulder and the prosthesis, the situation differs from that with the switch controller. With an EPP controller, the cable is a link between the shoulder and a prosthetic limb segment, the forearm, that moves relative to the socket. When the shoulder is elevated against the restraint of the cable, the elbow flexes and raises the forearm, reducing the cable tension. As long as the minimum force needed to cause the elbow to flex is lower than the force needed for the shoulder to displace the socket, the shoulder should be able to be elevated through a significant portion of its range.

Both the threshold force to flex the elbow and the shoulder excursion corresponding to the full range of movement of the prosthetic elbow can be varied independently in the prototype EPP controller.

CONCLUSION

The SD socket with shoulder cutout achieves the desired stabilization and support of the prosthesis while allowing relative shoulder displacement for component control. The next stage is to implement this socket design in a prototype SD-EPP prosthesis to test its applicability in clinical trials.

ACKNOWLEDGEMENT

The authors acknowledge the contribution of John N. Billock, C.P.O., Clinical Director, Orthotics and Prosthetics Rehabilitation Engineering Centre, Warren, Ohio, whose designs for plastic frame-type SD sockets provided the basis for the prototype EPP-SD socket.

The authors also acknowledge the support of Veterans Administration RR&D funds administered through the VA Lakeside Medical Center, Chicago.

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23.2 THE RESIDUAL LIMB/PROSTHETIC SOCKET INTERFACE: NORMAL STRESS AND SHEAR STRESS

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ABSTRACT

Residual limb/prosthetic socket interface normal and shear stresses have been recorded on below-knee amputees during walking trials. Results show variability between steps in a trial and between measurement sites in the same step. To better understand this variation, steps will be analyzed individually using an analytical mechanical model that accounts for tissue geometry, material properties, and shank loading conditions.

INTRODUCTION

A cause of below-knee amputee residual limb breakdown is an unfavorable normal and shear stress distribution at the residual limb/prosthetic socket interface. Prolonged static normal stress can cause necrosis (1); excessive dynamic shear stress can cause mechanical failure of the intercellular bridges in the epidermal *stratum spinosum* (2).

The goal in this work is to achieve a better understanding of interface stress mechanics. Interface normal and shear stresses are recorded at several locations during walking trials. Stress pattern differences between sites and between steps are investigated.

METHODS

A "skin fit" patellar tendon bearing socket designed by certified prosthetists is fabricated for each subject. Each prosthesis is completed with a Berkeley Adjustable Leg®, Seattle Lite Foot®, and latex sleeve suspension.

Interface stresses are recorded during ambulation with instrumentation described previously (3). Briefly, custom-designed transducers are placed in mounts affixed to the socket external surface such that they project through holes in the socket wall (Figure 1). The transducer sensing surface is a Pelite® disk. It lies flush with the surrounding Pelite® interface liner. No foreign material is introduced to the interface environment and the transducers do not protrude into the skin. Instrumentation measurement errors are 2.6% full-scale for shear stress and 2.7% full-scale for normal stress.

Interface normal and shear stresses are recorded at a 125Hz sampling rate at four sites of interest during the central 5 seconds of an 8-second walking trial (velocity 1.7m/s). Forces and moments in the prosthetic shank are recorded simultaneously with the interface stresses. Usually four steps are recorded in each trial.

RESULTS

Interface stresses are shown for a single trial (Figure 2) and during single steps from several trials with the same prosthetic alignment (Figure 3) (right-legged amputee). Analysis of 38 steps from the same subject show peak resultant shear stresses from 17kPa to 61kPa at anterior sites and 10kPa to 56kPa at posterior sites.

DISCUSSION

Peak stress magnitudes for each channel are similar for different steps. However, the shapes of the waveforms differ between steps in a trial (Figure 2) and between steps from different trials (Figure 3). The amputee probably compensates to achieve a stable gait and in doing so does not load the prosthesis the same in each step.

Quantitative analysis of averaged waveforms to study interface mechanics is not used because of variation between steps. Steps will be analyzed individually.

The geometry and material properties of the surface and underlying tissues are considered in interpreting this data. A mechanical finite element model of the residual limb and socket is being developed. Shank loading conditions collected simultaneously with interface stresses will be used as loading conditions in each step.

ACKNOWLEDGEMENTS

This research is supported by: The Whitaker Foundation, Department of Veterans Affairs, and the Bioengineering Department, Rehabilitation Medicine Department, and Graduate School at the authors' university.

FIGURE 1: An instrumented socket with transducers positioned in two of four anterior measurement sites. (cable not shown). Inset: transducer close-up view.

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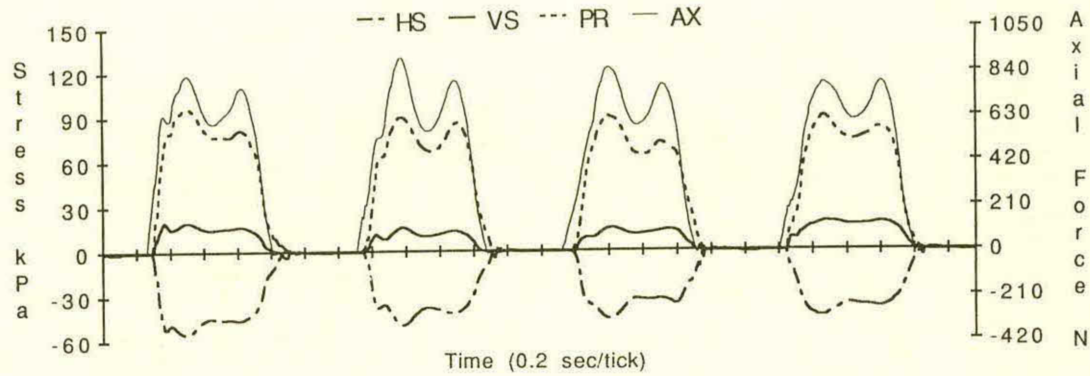

FIGURE 2: Interface stresses from an antero-distal site and shank axial force (AX). A positive load is defined as stress applied to the sensing surface. The positive horizontal shear (HS) direction is clockwise when viewing the socket from above; the positive vertical shear (VS) direction is downward; and the positive normal (PR) direction is outward.

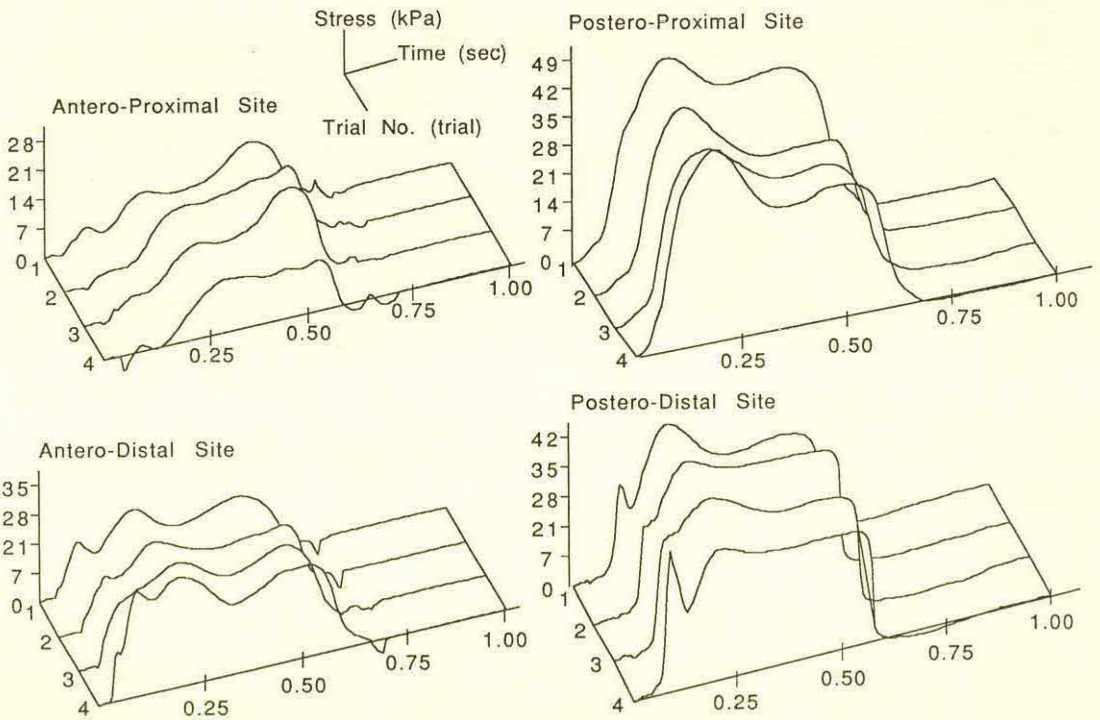

FIGURE 3: Vertical shear stresses for single steps from four separate trials.

23.3

FABRICATION OF A PENILE FIXTURE FOR INTRACAVERNOUS INJECTION THERAPY FOR IMPOTENT MALES WITH SPINAL CORD INJURY

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ABSTRACT

Intracavernous injection of vasoactive drugs has emerged as one of the most popular and controversial topics in the management of impotent males. The application of this technique has indicated short term success in many adult males. The SCI Unit at MetroHealth Medical Center has selectively treated several SCI males with this treatment regimen. With the quadriplegic male the regimen requires the assistance of a partner. A self injection jig was designed and fabricated by these writers to allow self injection of papaverine and phentolamine in spinal cord injured males.

INTRODUCTION

In disabilities such as spinal cord injuries sexual function is impaired due to the inability to achieve an erection. In our attempts to improve the quality of life in persons with disabilities sexuality is routinely addressed. Many of our patients have been requesting information and treatment with intracavernous injections of papaverine and phentolamine. Through this regime erection is achieved by relaxation of the corporal smooth muscle and subsequent arterial dilation.

The Department of Physical Medicine and Rehabilitation provides long term care for its SCI patients through our outpatient clinic. If this medical treatment is desired a partner must facilitate the injection routine. Some partners, whether they be disabled or ablebodied, may find this procedure unappealing. A self injection fixture was discussed and a prototype model fabricated to all allow a person with minimal hand function to administer his own injections.

METHODS

The device consists of four basic parts. A commercially available medicine bottle holder, a custom fabricated syringe extension, a gull wing base and an L- shaped trough.

The custom fabricated devices are made of low temperature plastic splinting material (orthoplast or polyform). The gull wing harness is placed between the person's thighs, immediately in front of the groin area. The base conforms to the contour of the thighs to aid in stability of the device. The trough, into which the penis is placed, is attached atop the base using hook and loop fasteners (velcro) A strap with hook and loop fasteners, attaches to the trough, and is used to secure the penis in the trough. The strap has a D-ring hardware end to allow securement by the spinal cord user. The trough is designed to alternate sides thereby reducing the potential problems which could occur after repeated injection.

A commercially available insulin bottle holder is used to stabilize the bottle of papavarine or phentolomine. Suction cups or dycem can be used to prevent the bottle holder from sliding or it can be clamped to a counter top, sink, night stand, etc.

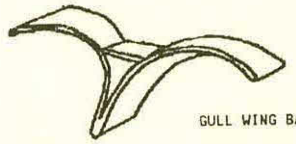
An adapted loop type handle, also fabricated from low temperature plastic, enables injection of the drug with very limited hand function, using only one hand. The handle snaps on and off with minimal effort to accommodate changing injection syringes easily and quickly.

DISCUSSION

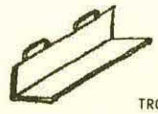
There exists today, only a few medical treatment methods for treating impotence in spinal cord injured males. Penile prosthesis, synergist erection systems and vasoactive drugs treatment are three methods of enhancing the sexual well being of individuals with spinal cord injury. The use of vasoactive drugs is a relatively new phenomenon but has gained much attention and interest in both the medical community and in the patient group affected by impotence.

FABRICATION OF A PENILE FIXTURE

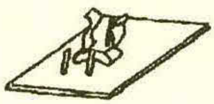
The fabrication of a custom made injection fixture allows some spinal cord injured patients the availability of managing his own sexual practices. Further investigation as to the effectiveness of this regime should continue. If the medical efficacy is sound this type of fixture should be refined and prescribed in patients wishing to manage this aspect of their lives.



GULL WING BASE



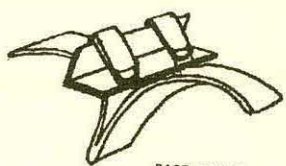
TROUGH



BOTTLE HOLDER

ADPATED LOOP TYPE HANDLE

LOOP HANDLE ON SYRINGE



BASE AND TROUGH (WITH STRAPS)

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23.4

Fabrication Methods For Molded Protective Headgear

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ABSTRACT

The need for more effective individualized headgear became apparent when we were no longer able to adequately provide protection for a developmentally disabled client who exhibited self abusive behaviors. A project to design and fabricate adequate equipment was instituted using methods and materials which met the requirements of each of our outlined goals.

INTRODUCTION

The initial goal of this project was to develop protective headgear for a particular individual who resides at our facility with a severe self-abusive behavior disorder. This protective gear was to be implemented in conjunction with established behavior modification techniques in addition to one on one care during periods of exacerbated behavior swings. This client required head gear as a result of wound sites located on the forehead which threatened her well being due to the inability of the the site to accept multiple attempts at skin grafts with repeated bouts of local infection from continuous injury to the area. Protective gear which would offer impact protection and relief from further abrasion to the insulted area was required.

Up until this time hand sewn vinyl helmets with fiberfill batting and commercially available hard shell and foam filled helmets with combinations of face shields had been used. All required constant modification and repair due to less than adequate fit and the fatigue of materials. Hygiene of the helmet itself was also a concern due to the risk of reinfection from a helmet which could not be adequately santized.

METHODS

Drawing from experience with techniques used in orthotic fabrication and adaptive seating we set out to produce a helmet true to the anatomical contours of this particular client. Fabrication materials which would meet the stringent equirements of continuous use under extreme conditions were sought. It was also our hope that a more exacting fit might produce a greater acceptance to wear the helmet by decreasing the incidence of its slipping down over the eyes or ears causing sensory deprivation or abrasion to the injured area thus producing pain. A mold of the individuals head would be required but we were reluctant to do a circumferential plaster wrap due to difficulties with cutting it off in addition to creating negative behavioral effects due to the invasive manner of this type of casting.

We chose a casting method using a flexible membrane filled with polystyrene beads and air evacuation to achieve a negative impression. The client was prepared by placing an elastic tubular orthopaedic stockinet cap over the entire skull and the area of injury outlined so that it would be demarcated in the plaster splinting negative. The client was placed in a supine position with the membrane at shoulder level with enough to encircle the top of the skull as far forward as the forehead and laterally encompassing the ears foreward to the temporal area. This would supply us with a negative impression of the entire skull less the forehead. Vacuum was pulled with the membrane being worked in closely to all areas around the skull. Since slight pressure is produced by this process we chose to place traditional plaster bandage splints over the forehead where the actual injury site was located. Quick setting bandage was used to hasten the procedure. As soon as this plaster forehead area set this section was removed and the client would thus not be required for the laying up of the plaster bandage for the posterior section of the mold. When the posterior section was dry the membrane was allowed to fill with air and pulled away from the posterior plaster section. Anterior and posterior sections were joined and filled with plaster with a pipe section placed in the center for easier handling. This was prepared and finished using traditional casting methods. The area of injury was built up so that a concavity would result in the positive form to reduce the chances of abrasion to the injured site. This positive bust would be used as a form to perform all molding procedures. In order to fulfill the requirements of providing impact resistance a viscoelasticfoam was chosen. Dynamic Systems Inc. Liquid Sun-Mate foam was used "because it can absorb tremendous impact forces. No other ordinary foam can match this performance range[1]". To provide sufficient liquid components to complete the helmet in one pour approximately ½of a standard unit which is usually enough to complete one standard size foam in place seat unit was used. Tó fulfill the requirements of impact resistance further, as well as provide cosmetic and form symetery properties to the finished product a standard two piece adjustable plastic hockey helmet was chosen for a shell. The bust would be placed inside of the hockey helmet shell and spaced equally from the top and sides this would determine the thickness of the foam liner. In this case that thickness turned out to be approximately 1½ inches. The bust was coated with a thin film of Vaseline to aid in the easy separation of the foam from the bust. The bust would finally be placed in a plastic bag to contain the liquid foam during the foaming process. A standard plastic face shield was secured to the front of the helmet to further control the expansion and contain the product in the helmet section during foam expansion.

Following the directions outlined in the Dynamic Systems Inc. Liquid Sun-Mate Foam-In-Place Instructional Manual, the medium density foam kit was prepared, mixed and poured into the helmet and bust combination. The resultant foam liner was trimmed to allow maximum protection to the client while producing as cosmetic a product as possible. Ear holes were provided to maxamize sensory input. The foam liner was smoothed and final shaping was accomplished on a trautman carver using a rasp attachment.

To meet the hygeine requirements of the helmet a coating of Dow Corning #732 RTV Silastic was placed around the entire foam insert. This would allow the helmet to be cleaned with mild detergent solutions on a daily basis and a more organism specific disinfectant when necessary.

RESULTS

The fabrication of this client specific item of protective headgear allowed us to attain the level of protection desired using a process which we were able to control within the mechanical and technological capabilities of our facility. Modifications were possible in house and multiple liners could be produced with relative ease and consistency of the product. A foam liner was sent to Danmar Products Inc. and prepared with their vinylcoating after the addition of a 1/8 inch covering of plastazote to prevent the absorption of solvent contained in the vinyl dip. This process provided options to our adaptive equipment personnel in fabrication posibilities by using an already proven coating for headgear to yield a durable and cosmetic product.

ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of Mr. Richard Ghizzone C.P.O. of Jack Gold Surgical Associates for his assistance with concepts and hands on fabrication and molding techniques. Dynamic Systems Inc. for their technical assistance in providing the foam and techniques for using foam in place technology. Danmar Products, Inc. for their assistance in providing a suitable coating system for the helmet. The staff of North Jersey Dev. Center for their continuing dedication to providing the clients of N.J.D.C. with the best possible care available.

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SPECIALIZATION IN TECHNOLOGY SERVICE DELIVERY: WHAT IS AN INTERFACE SPECIALIST?

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ABSTRACT

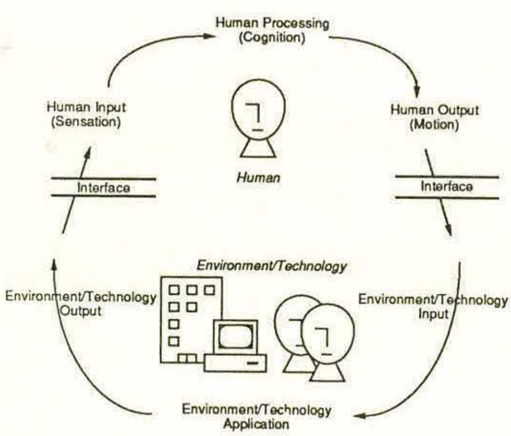
As service delivery in assistive and rehabilitation technology has matured, better role definitions and clarification of team member responsibilities has become necessary. While there continue to be no absolute definitive team member delineations, over the past decade the Trace Center and the Communication Aids and Systems Clinic (CASC) at the University of Wisconsin-Madison have begun to obtain a better grasp of the necessary team components for service delivery in the augmentative communication and computer access areas. One role which has gained a much better definition is the *interface specialist*: the team member who focuses specifically on optimizing the user's ability to operate a system.

This raises questions with serious policy implications. Adding another specialist on a technology service delivery team has obvious fiscal implications for society as a whole. Policy makers might inquire whether an additional team member is in fact required. While quantitative research is needed to quantitatively answer this question, this paper provides some initial data and discussion. Three questions are posed.

WHAT IS AN INTERFACE SPECIALIST?

In order for a person with a disability to use a communication device or a computer, they need to be able to control the system (input) and to understand the information that the system displays (output). Figure 1, based on Meister (1971) and Chapanis (1976) (from Smith, in press) displays this fundamental relationship between the human and the technological system. The role of the interface specialist is to understand the particular input and output needs of both the human and the technological device. In the context of persons with disabilities, this means that the role of the interface specialist is two-fold. First, the input and/or output of the device may need to be modified or adapted to match the capabilities and limitations of the human being. Second, the human being may need to adapt to the technology environment through either training or orthotic types of supplemental technologies. Usually, for optimal communication and computer system interface, adaptations or modifications are required for both the human and the technology ends of function.

Figure 1
Human-Environment/Technology Interface Model

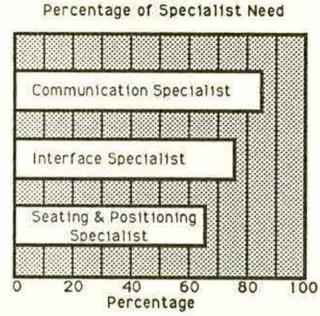


DO WE NEED AN INTERFACE SPECIALIST?

To begin to answer this question, this study performed a client needs analysis and a team function analysis. The client data analysis entailed both a staff survey and a case record review.

For the staff survey, CASC team members listed positions that they deemed important for augmentative communication and computer access evaluation and intervention. 100% of the responses listed a team position whose chief responsibilities focused on control, display, and overall component design. The survey also elicited the percent time that an interface specialist was thought to be needed for CASC evaluations. This mean average percentage, as estimated by CASC personnel, was 76.5%. This compared to 84.5% for a communication specialist, and 65% for a seating and positioning specialist. (See Figure 2.) These were the three positions listed by all team members as being necessary. Other positions listed included computer hardware/software specialist, social worker, engineer, and special educator.

FIGURE 2
Percentage of Specialist Need



Note that the data show that none of the three primary positions are required 100% of the time. Clinically, this has been shown to be true. For example, an interface specialist is not required when selecting vocabulary for a communication aid. A communication specialist would not be needed when a client (such as someone with spinal cord injury) has intact speech and language, but needs an adaptive writing system. A seating and positioning specialist would usually not be necessary for an ambulatory client.

The case record review consisted of an analysis of 156 CASC clients, sampled every other week between July 1987 and June 1989. It revealed that 85.3% of the clients required interface evaluations or interventions.

For the team function analysis, duties required by the augmentative communication and computer access team at CASC were listed. Eight functions were listed under system design and selection. (See Figure 3.)

Figure 3
Function Analysis: System Design and Selection

1) Evaluate and obtain proper seating and positioning.
2) Evaluate and obtain optimal control of the communication or computer system.
3) Evaluate and obtain optimal display and feedback from the communication or computer system to the user, as well as to others requiring information.
4) Evaluate and obtain proper workstation or communication system design (including placement of various components).
5) Evaluate and obtain appropriate vocabularies and language structures for the system.
6) Evaluate and train optimal interpersonal interaction strategies.
7) Evaluate and obtain proper software and hardware to meet the application requirements of the communication or computer environment.
8) Assess and obtain appropriate environmental support for implementation of the communication or computer system.

This list highlights the spectrum of expertise required in a comprehensive augmentative communication and computer access center. Examining this list, we can see that certain groups of functions require different types of expertise:

Seating/Positioning

1) Seating and positioning

Interface

2) Optimal control
3) Optimal display and feedback
4) System design (including placement)
7) Software and hardware

Communication

5) Appropriate vocabularies and language
6) Optimal interpersonal interaction strategies
7) Proper software and hardware
8) Appropriate environmental support

WHAT QUALIFIES ONE AS AN INTERFACE SPECIALIST?

Several skills qualify an individual as an interface specialist. First, knowing the impairments and the dysfunctions relevant to the populations using communication and computer systems is critical. Second, familiarity and working knowledge of the various interface technologies relevant to communication and computer systems is essential. Third, a fundamental understanding of the communication and computer applications which the individuals will be using is vital. Fourth, an interface specialist needs to be comfortable with (although need not be expert in) all functions of the augmentative communication and computer access team. Lastly, the interface specialist must be competent not only in selecting best technology, but training the individual to increase their motor, sensory, and cognitive skills related to interfacing technologies.

In the Communication Aids and Systems Clinic, interface responsibilities have been shared by four different disciplines, including all of the key team members (educator, electrical engineer, speech and language pathologist, occupational therapist). Individuals serving in the leading interface role have had formal training in engineering and occupational therapy. Traditional assistive and rehabilitation technology professionals can serve as effective interface specialists; however, extensive additional on-the-job and academic training is required. The electrical and mechanical engineer would require additional training in the therapy sciences. The speech and language pathologist would require additional background in sensory-motor, and technology areas. The occupational therapist would require additional training in technology.

CONCLUSIONS

The need for an interface specialist in augmentative communication and computer access evaluation and intervention programs has been highlighted in this paper. The ramifications of developing the role of an interface specialist, however, lead beyond communication and computer use. Many assistive and rehabilitation technologies such as environmental control systems, powered mobility and robotics all have needs for input and output evaluation and recommendations. Consequently, the role of interface specialist may not be limited to application in augmentative communication and computer access, but may be a generic responsibility in assistive and rehabilitation technology service delivery.

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THE HASBRO-ALABAMA POSITIONING NETWORK

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Abstract

The purpose of HAPN, a statewide network is to improve the provision of therapeutic positioning, mobility, and technology-related services to children. HAPN provides services in one central site, in two satellite centers, and through a mobile van service. Components of the program include training local practitioners, assessment and prescriptive services to individual clients, product evaluation, and technical assistance. The project has been successful in providing good quality and effective services in several local cities through the development of a therapist and vendor network supported through a central resource site.

Introduction

Few of the estimated 1200 multihandicapped children in the state receive the comprehensive and integrated positioning, mobility, and technology services they need. Many children receive some services through school systems, through state agencies, and from private physicians and therapists. The services received often have been technologically outdated, fragmented, and, when more appropriate, very distant from the individuals' homes. In a state where there is the potential for good positioning, mobility, and technology services, the problems of these children are unfortunate and unnecessary.

Background

We have been involved with therapeutic positioning, mobility, and technology services for individuals with severe impairments since the mid-1970s. In the Fall of 1988, the Hasbro Childrens' Foundation awarded a two-year grant to develop and enhance a multifaceted positioning and mobility program. Three staff members were hired to assist existing staff to begin to build the network through the grant.

Methods

Community meetings were held in distant population centers to inform, educate, and entice community participation into a network of parents and service providers interested in positioning, mobility, and technology. Training workshops were held to ensure that a basic level of common knowledge and philosophy preceded the delivery of services to clients. Local steering committees were formed to allow as much direct management of volunteer personnel as possible. Local clinics were established, therapists and vendors trained, and referral patterns developed. Inservices in conjunction with local clinics have continued to provide local practitioners with new product information, new insights and assistance in the local change process, and opportunities to tempt participation from more service providers than initially interested.

Results

Sixty-four (64) clients were served in the central site in 1989. With forty-four (44) state-based practitioners trained in 1989 and 14 clinics held in satellite sites, forty (40) clients have been served in satellite sites. The technology-dedicated mobile van became operational in February 1990. Vendor and therapist expertise has grown, and additional and more convenient service has been delivered to clients, both adult and children through the Network efforts. Training workshops have helped to increase the number of service providers and have served as a way to maintain the common philosophy and knowledge base considered necessary in this early phase of the life of the network.

Discussion

While the primary goal of the project has been to expand quality positioning, mobility, and technology services in distant parts of the state, it is significant that we have also provided assistance in changing service delivery patterns, quality assurance, and enhancing self-confidence and autonomy of practice for local practitioners. We feel the initial steps in the development of the network are successful. But the project is not yet over. A main outcome objective is to have community supported and independent clinics in each satellite site. Other communities in our state have been targeted for similar service delivery amplification in the next several years, so that local practitioners can effectively provide positioning, mobility, and technology services to local users.

Conclusions

The development of a statewide network for training, service delivery and technical assistance is an effective means of providing positioning, mobility, and technology services to individuals with disabilities in a large, primarily rural, state.

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Our thanks goes to the Hasbro Childrens' Foundation for the vision and faith they have shown in funding this project and to the university for provision of personnel, space, and other indirect resources.

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A University-Based Rehabilitation Technology Project

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Abstract

A university-based rehabilitation technology project is being implemented by a multi-disciplinary team of faculty and students. The model developed has enhanced efficiency in that this team has direct involvement in a wide range of factors involved in rehabilitation technology, including direct consumer service delivery, research and development, in-service and pre-service education and training, and information dissemination and management.

Background

Technology is becoming increasingly important in expanding the opportunities for people with disabilities in all aspects of their lives; it is a necessary, albeit insufficient, adjunct to other services for increasing their choices in home, educational, vocational, and social settings.

Professionals from a variety of disciplines play a role in the field of rehabilitation technology. Basic scientists do research and develop new ideas, refine current technologies, and increase the overall knowledge of the field. Other disciplines evaluate, fabricate, field-test, and market products. A myriad of service providers and rehabilitation specialists perform needs assessments and provide direct services and training using available technologies. Information specialists gather data involving products, services, and research developments for purposes of sharing knowledge and expertise on regional and national levels.

If the consumer is to receive maximal benefit from the various aspects of rehabilitation technology, those aspects must be effective and, more importantly, coordinated. A unique University-based project in rehabilitation technology has been developed, which has responsibilities across the spectrum of areas that require coordination: basic and applied research, fabrication, re-evaluation and design modification, education and training, and information networking and dissemination.

The Team

The project is being implemented by a multidisciplinary team of faculty and students. The team consists of an electrical engineer, occupational therapist, physiologist, and biomechanist, with collective expertise in the areas of rehabilitation, bioengineering, and ergonomics.

The Project

The first level of referral to the team is for an initial consumer assessment and evaluation. Following a review of pertinent background information, the team makes an on-site visit to the consumer. One objective for the initial assessment and evaluation is to provide the Vocational Rehabilitation (VR) counselor with additional, more specific information about the person's abilities prior to actual vocational placement. Another indication for referral is identification of a potential vocational site. The objective of the on-site visit is to perform a discrepancy analysis between the client's abilities and the multiple demands of the task. Information is gathered from a number of sources, including the consumer, family members, co-workers and supervisors, job developers, etc., to ensure recommendations are consumer driven.

An on-campus team meeting is then held, where the evaluation results, including videotape footage, is analyzed. A range of ideas for adaptations are brainstormed and a specific set of recommendations are forwarded back to the VR counselor.

Other types of services provided are professional engineering services and training. Professional engineering may include simple electronic or mechanical fabrication or ergonomic work-site modification. Training may include computer program training or electronic device familiarization for either service providers or clients.

Key to the success of a service project such as this at a university setting is the incorporation of teaching and research. Graduate students majoring in bioengineering and health and human services are funded by the project and are involved in referral, site visits, team meetings and device fabrication. Students are also encouraged to develop parts of the project into graduate research topics. Undergraduate students in engineering, and occupational therapy also have the opportunity to participate in the project, with the objective of giving them exposure and experience in rehabilitation technology and service delivery.

The team is also establishing itself as an information resource that can be accessed by consumers, state agencies, and rehabilitation professionals. It has conducted several in-service training workshops for VR counselors, evaluators, and other rehabilitation providers. The team now has access to several national databases which will allow networking on all aspects of technology: products, services, and programs.

<u>Summary</u>

This university-based rehabilitation engineering project involves activities in a number of rehabilitation technology components, from basic research to direct service delivery. Because all of the above activities are done by the same group of professionals, efficiency and accountability are enhanced, ensuring that people with disabilities will realize technology's full benefits.

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USE OF TECHNOLOGY TO CREATE EMPLOYMENT OPPORTUNITIES FOR PERSONS WHO HAVE COGNITIVE DEFICITS

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ABSTRACT

The use of rehabilitation technology to enhance employment opportunities for persons who have physical disabilities has been well documented. The advent of supported employment initiatives which place persons with cognitive deficits in competitive employment in the community has created the need to provide means for these persons to be productive and do quality work. Technical devices can be utilized to enhance productivity and insure quality of work performed by such workers. The use three such devices is described and results are presented.

DEVICES

Pacing of tasks on jobs is a major concern for all workers. It is a particularly difficult problem for the person who has limited attention span and has difficulty "staying on task". Varions kinds of devices have been used to help overcome this problem. A light coupled to an electronic timer which has adjustable settings can be used to indicate task completion be a momentary flash of the light. The adjustable setting feature permits the device to be used on different jobs. The light may also be used to indicate the time to begin a task. The most effective way to use a light and a timing device has been to find a way to reset the timer prior to the light flash if the task is completed by the worker within the allotted time for the task. This technique seems to provide sufficient challenge to most workers to "beat the clock". Use of timing devices to indicate proper pacing has created opportunities for employment for some persons who could not be competitively employed otherwise.

Counting of objects is a common requirement in industry. Packaging of items nearly always requires that an accurate count be made of the items to be placed in the package. Various means are used such a weighing and filling an appropriate number of slots or compartments provided in the package itself. Requirements for counting a few items at a time usually are not satisfied by using external helps. Workers simply count "one, two, three,...", etc. For a person who is otherwise capable to do the job but cannot count, this simple task creates the only barrier to getting the job. Technology now offers the use of proximity sensors which can pick up the presence of objects as they are passed near by. These sensors can be coupled to counting devices to indicate numbers of items. Such devices are inexpensive to make, easy to use, and can make counting jobs available to the subject personnel.

Perhaps the most difficult problem to address on any job is that of behaviour. Persons with mental disabilities often display behaviour that is unacceptable in competitive employment. In the supported employment realm behaviour is often modified by a job coach who maintains close contact with the worker at all times. The desirable goal is to reduce the required contact time for the job coach. Recently, use of a small casette player of the type to wear on the belt and using light weight headphones has been tried to provide instructions to workers. In cases where repeated instructions are necessary a closed loop casette of one to three minutes duration has been tried with positive results. In one case an individual that was performing at 15% of standard on the job achieved 85% of standard by using one of these devices. Instructions are more effective when recorded by the job coach or someone else who is familiar to the worker. In any case the instructions must be specific to the individual. Use of these devices has also been beneficial in training settings and have been discarded after use for a brief period of time. Many applications have yet to be tried using taped instructions, but trials to date indicate that before "giving up" on a situation they are worthy to be explored. Costs for tape players of this type range from $15.00 to $50.00 making such trials inexpensive.

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Achieve: Achieving Employment and Independence with Assistive Devices

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Introduction

This paper will discuss the first year of a model program to 1) assess consumer satisfaction with assistive devices, 2) establish a structure for identifying the appropriate assistive device for specific disabilities and 3) expand employment opportunities to persons who are potentially employable through the use of assistive devices. Physically disabled employed adults who use assistive devices in their work are the participants in the first step in this program, followed by physically disabled unemployed adults who potentially could be employed by using assistive devices.

1. Development of assessments.

Assessments are being derived from the users, employers and rehabilitation team. These assessments establish a structure for identify the appropriate assistive device for each physically disabled. The assessments will help users maximize the effectiveness of their devices, and identify areas for job growth.

2. Establishing a structure for identifying appropriate assistive devices for specific disabilities.

Persons successfully using assistive devices in the work place demonstrate that their particular disability does not preclude gainful employment. Further, the presence of a device in the work environment indicates a specific kind of work that can be performed by a person with a specific disability using an assistive device. Examining the job identifies work tasks which a person with a severe disability can perform with an assistive device. The tasks represent potential employment opportunities for other persons with severe disabilities.

A system is being developed to match jobs types, assistive devices, and persons with disabilities to make a successful employment situation.

3. Expand employment opportunities to persons who are potentially employable through the use of assistive devices.

The information gained from those who are already successfully employed will be shared with those physically disabled persons who are unemployed but who are interested in employment opportunities. The insights of those already employed on what can and cannot be expected from the devices and job matches is invaluable to the team and to other the disabled individuals who are interested in employment. This information will be shared by the physically disabled who are already employed with the physically disabled who desire to be a part of the work force.

Those interested in employment will be assessed by the rehabilitation team, given recommendations, trained on the recommended equipment, and offered the opportunity to train using the equipment with local employers.

Conclusions

Persons with disabilities can use assistive devices to perform tasks required in employment. Assistive devices can create vocational opportunities -- the person may be employable with the device but not employable without it, or the device may enhance vocational outcomes --the person may work more effectively with the device than without it. In either case, the presence of assisted devices in the work environment presents several opportunities to improve or expand vocational rehabilitation services to individual with severe disabilities.

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COLLABORATIVE CONSULTATION: A MODEL FOR THE PROVISION OF ENABLING TECHNOLOGY SERVICES

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Introduction

Providers of enabling technology services are frequently cast in the consultant role. The traditional literature describes four approaches to the consultation process: the expert or behavioral, the medical, the mental health, and the collaborative model. The collaborative model is uniquely suited to the provision of enabling technology services.

Discussion

Idol (1986) defines collaborative consultation as an "interactive process that enabled teams of people with diverse expertise to generate creative solutions to mutually defined problems." The outcome is enhanced and altered from the orginal solutions that any team member would produce independently. This mutual interaction exists for the purpose of preventing or solving problems.

The collaborative model has been used successfully at many levels, in a variety of settings. Derived from a triadic model, its principles include equal participation and status which form the basis of interaction. With an emphasis on shared responsibility, this model assumes that each member of the triad brings different kinds of knowledge to each stage of the process.

The collaborative model capitalizes on the knowledge of all involved -- consultant, mediator(s), and the target individual. Consultant and consultee share expertise because of mutual responsibility. Individual roles are defined according to knowledge and resources, which are more easily shared because of increased communication between diverse professional disciplines. The provision of services based on needs facilitates an individual-centered, problem-centered approach.

Flexible enough to deal with a wide range of ages and abilities, the collaborative model can serve as a link between knowlege producers and knowledge consumers, and includes parents, family members, and individuals in all aspects.

The collaborative approach will be illustrated through examples of enabling technology centers in the United Kingdom and in the United States.

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COGNITIVE SKILLS ASSOCIATED WITH THE OPERATION OF VARIOUS COMPUTER INTERFACES

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ABSTRACT

Interface selection is influenced by both individual and task considerations. Thus, it is necessary to understand the cognitive skills underlying interface use, as well as how they are manifested in performance. This paper provides an analysis of some of these cognitive skills involved in the use of six different interfaces. Identification of these skills is the first step toward measurement of the portion of cognitive load in computer use attributable to the interfaces.

INTRODUCTION

Cognitive load has been perceived in a number of ways. It is commonly defined in terms of measurable task performance characteristics, such as relative efficiency and correctness in accomplishing a task. Another approach to cognitive load is resource allocation which focuses on the cognitive skills, such as memory or attention, which underlie the user's performance on a task. Potential sources of cognitive load in computer systems include the input mechanism, presentation/output format, task structure (including prompting and other responses), and symbol system (see Cress & Goltz, 1989 for more information). If the relative contribution of these different elements of the computer system to cognitive load can be isolated, it may be possible to compare the expected cognitive difficulty of unique computer-user-task combinations. The focus of this paper is the contribution of the input mechanism to the cognitive load of the computer system.

Most task analyses in the human factors literature are based on a performance estimate of cognition. For instance, the GOMS task analysis (Card, Moran, & Newell, 1983) is used to predict subject performance based on task characteristics of goals, operators, methods, and selection rules. The GOMS does not account for the cognitive processes underlying subject performance, other than recognizing short- and long-term memory as a simple input/output mechanism. This analysis allows estimates of task difficulty for a given task across individuals. However, task-based analysis schemes are limited when selecting an interface for client use across tasks and programs.

The present analysis generalizes necessary subject skills from interface characteristics, to allow estimates of cognitive difficulty across tasks using those interfaces. This analysis, in taking a resource allocation approach, presents some of the cognitive resources implicit in the use of each interface to accomplish a goal. For this paper, the goal is reduced to moving a visual object (such as a cursor) on the computer screen to a predetermined location.

Porter, Lahm, Behrmann and Collins (1986) outlined the cognitive requirements for general computer use, including: 1) intentional communication, 2) awareness of options and the ability to make conscious decisions about them, 3) ability to define goals and plan action sequences to attain them, and 4) a concept of past events and an ability to anticipate future events. According to Piagetian hierarchies, Porter et al. report that all of these should be present in a normally developing child by approximately 18 months of age. In addition to these requirements, some understanding of means/end relationships (understanding that the person's actions have an effect on subsequent events or responses) must be present before functional computer use is possible.

Research suggests that some interfaces such as the touchscreen are consistently easier to use (Chapman, Dollaghan, Kenworthy & Miller, 1983), and the following list identifies some of the differences in required skills for interface use which may contribute to cognitive load across tasks. Some of the cognitive skills specific to six different interfaces (the touchscreen, mouse, joystick, trackball, touchpad/keyboard with repeating function, and touchpad/keyboard without repeating function are reported below.

COGNITIVE SKILLS ASSOCIATED WITH SPECIFIC INTERFACES

Touchscreen

Moving a visual object with a touchscreen involves a 2-step process: touch the screen on the cursor, and drag the cursor to the intended location. Dragging involves maintaining contact with the touchscreen throughout the movement. While the computer program interprets the release of pressure from the screen to signal completion, the act of removing the finger from the screen is an intrinsic, unlearned stopping of an action rather than the execution of an intentional, independent movement. Therefore, this is not seen as an additional step in touchscreen operation. Necessary cognitive skills include:

- ability to differentiate between effective and ineffective means of touchscreen operation (e.g. touching the screen with one finger versus a whole hand, and limiting activity to the visual screen area).
- ability to anticipate the continued movement of the object along a planned trajectory in the presence of a delay between user action and screen response.

Mouse

Standard use of a mouse in moving a displayed object entails a 3-step process: clicking to pick up the cursor, dragging it to the intended location, and releasing the button to signal completion. The nature of the completion signal for the mouse, namely the release of pressure from the button, is motorically similar and electronically identical to the touchscreen. However, since the use of a mouse is a learned behavior, specific to computer operation, this movement is seen as a distant step in correct mouse operation. Necessary cognitive skills include:

- comprehension of mouse motion in one plane producing cursor movement in another plane.
- ability to divide attention between operation of device and effective monitoring of cursor movement.
- ability to determine the amount of mouse movement needed for the desired amount of cursor movement.
- ability to plan and simultaneously execute two actions (e.g. maintaining button click and dragging the mouse).

Switch Joystick

Use of a switch joystick in moving a displayed object entails a 2-step process. The user must move the joystick in the desired direction, and return it to the neutral position when the cursor reaches the endpoint. Necessary cognitive skills include:

- comprehension of stationary joystick positioning in one plane producing continuous cursor movement in another plane.
- ability to divide attention between operating device and effective monitoring of cursor movement.
- comprehension of the relationship between amount of cursor movement and duration of joystick deflection.
- ability to plan timing of joystick release to correspond with the anticipated time of target acquisition.

Trackball

Use of a trackball in moving a displayed object involves an undetermined number of small steps. The user must move his hand over the trackball repeatedly to move the cursor the desired distance and in the desired direction. Upon reaching the endpoint, the user must signal completion by pressing a button. Necessary cognitive skills include:

- comprehension of the relationship between distance moved on the trackball and distance moved by the cursor.
- comprehension of the necessity for repeated movements for continued cursor movement.
- ability to continually re-evaluate the discrepancy between the current cursor position and the desired location, and to revise movement patterns accordingly.
- ability to divide attention between operation of the device and effective monitoring of cursor movement.

Touchpad or Keyboard:
standard repeating function on

Use of the cursor keys on a keyboard with the repeating function on to move a displayed object involves an undetermined number of steps. The user must move the cursor on two axes toward the target, and may need any number of trials to refine final cursor placement. In many programs, upon reaching the endpoint, the user must also press a key to signal that the task is complete. Necessary cognitive skills include:

- comprehension of movement in one plane producing cursor movement in another plane.
- ability to differentiate the function of each cursor key.
- comprehension of stationary key operation producing continued cursor movement.
- comprehension of relationship between the duration of key depression and amount of cursor movement.
- ability to divide attention between operation of the device and effective monitoring of cursor movement.
- ability to continually re-evaluate the discrepancy between the current cursor position and the desired location, and to revise key selection and activation appropriately.

Touchpad or Keyboard:
standard repeating function off

Use of the cursor keys on a keyboard with the repeating function off requires an undetermined number of steps to move a displayed object. Since each tap of a key corresponds to cursor movement only one space in the designated direction, the user must tap the key repeatedly in order to reach the target. As with the other keyboard method, the user must move on two axes toward the target, and may then need to press a key to indicate completion. Necessary cognitive skills include:

- comprehension of movement in one plane producing cursor movement in another plane.
- ability to differentiate the function of each cursor key.
- comprehension of necessity to make repeated movements to achieve continued cursor movement.
- ability to continually re-evaluate the discrepancy between the current cursor position and to revise key selection and activation appropriately.
- ability to divide attention between operation of the device and effective monitoring of cursor movement.

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KEYBOARD ACCESS TO THE APPLE MACINTOSH

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INTRODUCTION

The Apple Macintosh (Mac) is a popular computer platform for personal, educational, and professional use. The Mac operating system has advantages in its consistent windowed graphical user interface (GUI) and the seamless transfer of data between programs. The user interface is very friendly for those new to computing and allows experienced users to learn new applications quickly.

Although the user interface is intuitive, the required direct manipulation of graphic objects with a pointing device can be difficult for users with impaired physical abilities (1). This paper briefly describes the actions required for the GUI, and outlines some alternative access methods. This information should be useful to individuals who 1) cannot operate pointing devices, 2) are using the Mac and no longer need the GUI, 3) are considering the development of serial (e.g., Morse code) or on-screen keyboard emulators and need to evaluate their compatibility with keyboard input utilities.

USER INTERFACE REQUIREMENTS

The Mac is controlled by the interactions between a pointer on the screen and a variety of other graphic objects. Three actions are required of the pointer: 1) A *click* consists of a tap on the mouse button or an equivalent switch. Much like an electrical switch, a *click* activates specific graphic objects. For example, it may press a *button*, specify a preference with a *check box*, or select tools from a palette 2) A sustained *click*, i.e., a *press*, is usually used as part of the third action. 3) A *drag* involves a *press* while moving the pointer and is used to draw or resize an object, surround and select a group of objects for simultaneous manipulation, slide objects to another location, and often, to select commands from pull-down menus at the top of the screen. Menus may subsequently invoke windows requiring text and/or further pointer actions. Rather than providing commands, the keyboard, at the simplest level, is used only for text input.

ALTERNATIVE ACCESS METHODS

Keyboard mouse emulation. There are a number of alternative pointing devices available including head controls, trackballs, miniature digitizing tablets and touch screens. Each of these has different advantages and drawbacks for handicapped individuals, however, all require the precise motor control inherent in current GUI's.

With the release of system version 4.1, Apple began including *Easy Access*. It is a file that is integrated into the system during start-up and maps pointer movement and the mouse button functions to a set of keys on the numeric keypad. The mouse is moved one pixel at a time for single keystrokes and accelerates as a key is held down continuously. Using only *Easy Access*, it is possible to move the pointer, *click*, *press* and *drag*. There is another utility, *MouseKeys* (3), which provides keyboard mouse emulation, yet moves the pointer at a fixed rate. The acceleration, maximum speed, and clicking parameters are adjustable by changing the mouse settings in the Mac's *Control Panel*. These settings can be expanded further using the public domain utility *Pointer* (2)..

Macros. It very tedious to perform all individual pointer actions by direct keyboard emulation. There are a number of different macro utilities that can help to overcome this difficulty. Sequences of commonly used pointer actions can be recorded and assigned to a distinct keystroke. For example, <shift><option>9 can invoke a macro that opens the root directory window, expands the window to full screen size, displays its contents as a text list by choosing "by name" from the "view" menu, and finally, moves the pointer to the first file name.

Apple system version 6.0 include *MacroMaker*, which can record mouse and keyboard actions. It automatically loads user defined macros corresponding to the currently loaded application program and includes global macros that are always active. *QuicKeys* (5), is a third party utility that has been found to be more useful and sophisticated than *MacroMaker*. It includes a library of prerecorded global and application-specific macros. It can load any application program from a single keystroke, allows for editable sequences of macros, and displays and prints stored macro names and associated keystrokes.

Keyboard operation of menus. Menu items are the equivalent of command line entries in other operating systems. Apple, and most developers have incorporated some keyboard equivalents for menu items. Some users appreciate the increased efficiency of direct command selection without having to maneuver a pointer or wait for screen rewrites. There is an elegant shareware utility called *MenuMaster* (4) that enables users to permanently change or add a limited number of key equivalents to menus. Some newer applications include non-standard menus that are incompatible. Both MacroMaker and QuicKeys can be used with all menu items by recording the menu selections rather than changing the menus themselves.

Dialog boxes. Some menu selections and other user actions invoke *dialog boxes*. These are windows which appears as a warning or to prompt the user for information. They may include among other objects, a scrolling *list box* displaying the files in the current directory, numerous buttons, and *check boxes*. Apple has incorporated keyboard equivalents into some of these objects: <tab> emulates a *click* on the disk drive *button* or steps the cursor through any text fields that are present, <return> emulates a click *on* the default button, i.e., usually, the one with the bold border, the up and down cursor keys and <command> can be used to select files and navigate through the directory tree in the *list box*. Other objects are activated with the pointer. Macros are not useful for recording these actions because they interpret *clicks* based on coordinate positions and *dialog boxes* are not uniform in their content or arrangement. However, *QuicKeys* can assign keystrokes to *button* types as well as to a "next" and "previous" function to sequence through and activate any objects in a *dialog box*.

File management. Essentially all file management functions such as renaming, copying, deleting, and moving, are performed by directly manipulating icons within the Mac *Finder* . It uses folder icons to represent directories. When opened, these expand into windows displaying a variety of icons representing files and applications. This graphic environment is not static and therefore does not lend itself well to keyboard access. Some head way can be gained by performing a sequence of actions that uniformly arranges windows and icons. The example macro above describes this procedure. Subsequent macro can sequence the pointer through fixed intervals in registry with the icons and so on. Alternately, a non-graphic file management shell can be used in place of the *Finder*. *DiskTop* (5) includes keyboard equivalents for most its functions and rather than replacing the *Finder*, is invoked by a menu selection.

Keyboard function emulation. Apple's *Easy Access* includes a second function for single keystroke typists. *Sticky keys* enables a latching function for the modifier keys. Contrary to Mac User Interface guidelines, the display for sticky Keys provides only vague feedback regarding the status of the keyboard. This can be circumvented using the Mac's *Key Caps* . *Key Caps* displays a representation of the Apple keyboard that is currently attached and provides visual feedback of the status of all keys including those latched in software. All windows can be resized so that the modifier keys in *Key Caps* are visible at the bottom of the screen. Using the Mac's *MultiFinder*, *Key Caps* can be opened at system start up and remain in position while other applications are subsequently loaded and exited.

If a user has a sufficiently large range of motion, an Apple expanded keyboard can further augment the user interface. It has 22 additional keys which can be dedicated to specific macros as well as a fifth modifier key, <control>.

It is significant to note that Microsoft Word for the Mac has included many keyboard equivalents as well as a facility for accessing all of **its** menu's and dialog boxes using the numeric keypad. This feature does not however, work with the system level dialog boxes that appear within Word. It would be enormously useful if this kind of keyboard access system was available as an independent function of the operating system.

CONCLUSION

The information presented here can enhance the use of the Mac even for those able to use a pointing device. The options outlined can, each by themselves, make the Mac more accessible through the keyboard and can improve upon other access methods. The macro utilities described use the same consistent Mac interface so that even novice users may be able to create their own macros.

Using only keyboard access on the Mac does present some problems. There no standards established for keyboard equivalents for most actions so that macros customized for each application program are not portable to other applications. This may also result in distinct actions being assigned to duplicate keystrokes. Further, macros are activated with a single keystrokes. This increases the cognitive demand on users by requiring that they remember nonintuitive commands such as option shift left bracket. Macros are are also performed at maximum system speed so that the sequence of actions and events are invisible. This obscures the original user interface.

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TABLE 1 ESTIMATE OF HEAD MOVEMENT QUALITY

GOOD - possibly sufficient to use standard computer/typewriter keyboard, with head- or chin-pointer if needed.
LIMITED - possible use of special keyboard or partial standard keyboard.
VERY LIMITED - possible use of joystick, mouse, trackball, pointer or tablet.
SLIGHT - possibly sufficient to operate one or more switches.
NO functional head or neck movement.

TABLE 2

Subject	Diagnosis	Interface	Target size (mm)	Reaction time (s)	Holding time (s)	Accept time (s)	Net input rate. /min
C/1	MS	LROP on left	12.5	2.4	0	2.7	NR
C/2		LROP on right	6.0	4.6	0	1.2	NR
V/1	CP	chin joystick	12.5	5.6	0	1.5	NR
V/2		chin joystick	12.5	5.2	0	1.1	NR
V/3		chin joystick	6.0	5.7	0	0.8	NR
V/1		LROP on right	18.5	2.3	0	*	NR
V/2		LROP on right	12.5	4.3	0	0.6	NR
CC/1	N	LROP on right	6.0	1.0	0	1.3	42
CC/2		LROP on right	6.0	1.0	0.2	0.8	31
VS/1	N	LROP on right	6.0	0.8	0.1	0.5	49
ED/1	N	LROP on right	6.0	1.4	0	0.6	31
ED/2		LROP on right	6.0	1.4	0.1	0.6	30

KEY:
MS - multiple sclerosis
CP - cerebral palsy
N - non-disabled
* - test not performed
NR - no results given on test completion

TABLE 3

Subject	Target size (mm)	Reaction time (s)	Holding time (s)	Accept time (s)	Net input rate (items/min)
CC	6.0	0.6	0.2	0.8	34
	12.5	0.6	0.6	1.0	44
	18.5	0.7	5.0	0.7	94
	25.0	0.6	0.1	0.8	40
	31.0	1.0	0.2	0.8	31
VS	6.0	0.6	2.1	0.7	83
	12.5	0.5	0.3	0.6	69
	18.5	0.8	0.2	0.6	58
	25.0	0.8	5.0	0.3	72
	31.0	0.8	0.1	0.5	49
ED	6.0	0.8	0.1	1.1	32
	12.5	1.3	0.1	1.0	23
	18.5	1.1	0.1	1.1	49
	25.0	1.1	0.1	0.7	65
	31.0	1.4	0.1	0.6	30

The net input rate tests for the disabled subjects C and V yielded no results, not even zero. The results from previous tests had combined to give them conditions within which they could not perform. The results are derived from a combination of worst and best performances rather than a suitable weighting of each attempt, leaving the extreme performance to be recorded. This then forces the subject along unnatural paths through the tests with the consequence of no valid data at the end. In addition, the assessor has no access to the full data set and therefore cannot reject spurious data. Obviously, these subjects have an ability and the assessor needs to be able to determine the degree of ability.

CONCLUSION

The ACES package represents a major step in the right direction for quantitative assessment. The concepts and tasks for the five parameters of interface use are valid. However, since a written report is produced, it is imperative that the results it contains are accurate and fully representative of the subject's abilities.

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DIRECT SELECTION USING HEAD MOVEMENT: FIRST EXPERIENCES WITH A SOFTWARE ASSESSMENT PACKAGE.

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ABSTRACT

The ACES software assessment package [1] was used with severely disabled subjects to explore their use of a chin joystick and head mounted optical pointer. Three non-disabled subjects also performed the tests with the head mounted optical pointer. The test suite will be described and results presented. Whilst the parameters and tasks were appropriate, the presentation of the results led to an unrepresentative picture of the subjects' performances.

INTRODUCTION

Many man-machine interfaces utilise head movements [2], but little detailed work has been published on head movement characteristics of severely disabled people and the type of head movements required for efficient use of particular interfaces.

The ACES software package for IBM-PCs, is designed to produce an individual specification for an augmentative communication system for any disabled user including those restricted to head movements. The package includes program suites for client information, an evaluation planner, evaluation test programs for visual, auditory and motor skills, a report generator and device simulation. Test results are stored in the client information section and are included in the report. Only the tests for proportional control will be described here with their application to head movement assessment for direct selection.

MATERIALS AND METHODS

The assessor initially estimates head movement quality as defined in Table 1. Use of the interfaces associated with the group is then tested through a series of tasks. The interface is connected to the PC through the software security key. The following tests are offered for joysticks (with and without spring centering), long range optical pointer (LROP), touch pad and track ball: Reaction Time/Target Size Test, Holding Time Test and Net Input Rate Test.

In the test for Reaction Time/Target Size, the subject is asked to place a cursor within a square box positioned randomly on the screen. The test is repeated eight times for each box and the side decreases from 31mm to 6mm.

Holding time is the time for which a subject can hold the cursor on a target without releasing it, and accept time represents how long the subject holds the cursor on incorrect targets (accept time = 1.5 x longest time on empty cell en route to target). The test utilises a 3 x 3 grid of squares, the size being determined from the preceding test. One square is highlighted and the subject is requested to move the cursor to the highlighted square and keep it there. Times for movement and maintenance of position are recorded. This is repeated a further five times randomly.

The results from the previous tests are now combined in the final test which sets up a realistic selection procedure. This involves a 7x5 grid of squares, one of which is highlighted. The number of selections made is used to calculate the parameter called net input rate.

RESULTS

Results for all subjects are shown in Table 2 with the tests performed in the expected manner. The disabled subjects were assessed at weekly intervals in consideration of the variable nature of head movements. No results were given for the disabled subjects' performances of net input rate as they did not make any correct selections

The non-disabled subjects also carried out all tests for each target size and these results are shown in Table 3. The test suite was artificially interrupted to allow testing for each target sizes.

DISCUSSION

The tasks are suitable for non-literate people and are not bound up with 'game like' rules thus increasing their accessibility for those with learning difficulties.

All tests are accompanied with auditory cues for the different stages of the tests and can therefore be used by those with limited colour discrimination and mild visual problems. Visual and auditory skills should be defined prior to interface testing and should match those required by the end task.

Reaction times are of similar magnitude for each subject, as expected, and tend to increase slightly for the smaller target sizes. The disabled subjects had longer reaction times.

The essence of a direct selection is that the cursor is held in position long enough for selection to take place. From the definitions, holding time has to be greater than the accept time, otherwise incorrect selections would occur whilst traversing the grid. As can be seen from Table 2, holding times are less than the accept times for the disabled and some non-disabled subjects, even though V was a proficient chin joystick user. This leads to concern over the measurement of holding time. The worst attempt is recorded and that attempt may arise from the slight overshoot in homing onto the target. No allowance is made for this.

grasped and the time it is put to use). Exertion of force (X4) is the slight delay that typically occurs when a tack is pressed into a resistant surface. With practice most stationary, manual work can be described in these terms.

An example: The task of moving the hand about 12 inches to grasp a pen lying on an uncluttered flat surface and moving the pen about 6 inches to set it aside:

M4G1 - reach out 12 inches and get pen
M3P0 - move and drop the pen.

Alternatively, picking up the pen and moving it to a writing surface 6 inches from its original location:

M4G1- reach out 12 inches and get pen
M3P5 J2 - regrasp while moving pen to paper.

In the second case two differences will be noted in the Modapts description. After grasping the pen it is regrasped (J2) in preparation for writing as it is moved toward the writing surface and it is brought down at a precise location (P5) rather than dropped in a general location (P0). Although it is simple enough to time the entire sequence of work elements making up either of the above tasks it is not so easy to isolate individual times for each of the elements - they are short in duration and it is not clear where one element ends and the subsequent element begins. An algebraic technique, for instance Gauss-Jordan elimination, can be used to estimate individual element mean times from a set of different tasks, each task being timed in its entirety and a list of its work elements recorded.

THE EXPERIMENT

Nine able-bodied students were tested as were 9 disabled workers from a local sheltered workshop. Each group of 9 consisted of 5 male and 4 female subjects. Results from 27 dexterity tests were used to generate a customized Modapts compatible Worker Profile for each subject. The Worker Profile was used to predict each subject's performance times on 2 manual assembly jobs. The 18 subjects were trained on the 2 jobs and their performances were recorded. Analysis of variance (ANOVA) was used to determine the validity of the Worker Profile technique.

ANALYSIS

A mixed factor ANOVA test was conducted to compare the accuracy of the model in predicting work performance. As expected group differences were highly significant ($p = 0.0001$) and task differences were also highly significant ($p = 0.0001$). As desired model prediction and measured performance differed insignificantly ($p = 0.27$). An alpha level greater than 0.20 is necessary to accept a predictor as accurate, in this case alpha was 0.27 and the Worker Profile model can be accepted as an accurate predictor of work performance.

CONCLUSIONS

- PTS can be modified for an individual.
- Atypical work performance can be modeled.
- Disabled workers can use IE work methods.
- Algebraic techniques can help when sample size is small.

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PROFILING DISABLED WORKERS WITH A MODIFIED PREDETERMINED TIME SYSTEM 27.2

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ABSTRACT

This paper introduces the Worker Profile model, an assessment tool that is easy to administer, that assists in job selection and modification, and that is completely compatible with the predetermined time systems (PTS) used in most manufacturing facilities. Unlike work sample methods, a PTS assessment generalizes to many jobs. Unlike medical or social service assessments, a PTS tool is easily used by industrial engineers on the shop floor.

BACKGROUND

Industrial engineers have used predetermined time systems (PTS) for many years to describe work (1). PTS are sets of work elements that can be arranged in sequences to completely describe a wide range of jobs. Each work element is assumed to have a cost (either in terms of energy or time expended to perform) and the total cost of a task is assumed to approximate the sum of the costs of the individual elements (2). The technique allows industrial engineers to develop optimal methods for task performance (i.e., to minimize energy or time expended on the task) and to estimate performance times for assembly line balancing or for piece work payments. PTS have not been applied to the performance of disabled workers because they are based on the average able-bodied workers' manual abilities.

There is no simple direct way to modify PTS to account for performance times of the work elements of disabled workers (3). When a single element is timed in isolation acceleration and deceleration errors are encountered. Repeated performance of a single element results in unnaturally rapid actions. Frame-by-frame analysis of filmed work sequences is a time consuming and boring effort which is rendered almost worthless because it is difficult to visually detect the transition points between consecutive elements. Also, delays that occur during the performance of one element may be more correctly assigned to another element; when a reach is slowed while the worker visually selects one object to be grasped, the extra time should be associated with the grasp element for which it is required, not the reach element during which it occurred.

THE TECHNIQUE

The unique manual performance of disabled workers makes both statistical modeling and direct modification of PTS difficult; therefore, an algebraic modeling technique was developed. A set of dexterity tests, each using a different mix of work elements, was selected, administered and performance times recorded. Gauss-Jordan elimination method was used in a least squares sense to assign mean performance times to each of the work elements (4). The dexterity tests were selected from the Available Motions Inventory battery (5). The Modapts predetermined time system was used as a basis for the Worker Profile because it is in wide usage among manufacturers and is relatively easy to use (6).

The Modapts elements used in this study were:

M1 - 1 inch move or transport
M2 - 2 inch move or transport
M3 - 6 inch move or transport
M4 - 12 inch move or transport
G0 - make contact or touch
G1 - get easy to grasp, large object
G3 - get small, difficult to grasp object
P0 - place (drop) object in general area
P2 - place object along a line
P5 - place precisely at intersection of 2 lines
J2 - juggle or regrasp object
X4 - exert force on object

Modapts elements M1, M2, M3 and M4 are moves or reachs which involve a shift in the worker's locus of control in the work space. An able-bodied worker would normally do this by moving the fingers, hands or arms. A disabled worker would use headstick, mouthstick, prosthetic device, etc. A Modapts move may occur with the hands empty (i.e., reaching for an object) or with something in the hands (i.e., carrying an object to a new location). The Modapts elements G0, G1 and G3 are gets or grasps used to gain control of something. The P0, P2 and P5 elements represent the release or placement of objects that have previously been controlled. The juggle or regrasp (J2) involves repositioning an object already controlled, typically during a move to the location where it will be used (e.g., the regrasping of a pencil or a screw by the fingers during the movement between the time it is originally

It is interesting to note that **Moderate** postures are held more often than any other posture including the **Neutral** posture.

While the Stat-tablet provides a look at the postures held by workers the classification scheme used at the present time is quite arbitrary. The software does, however, allow for the parameters of the classification scheme to be changed as needed.

Future work will focus on developing criteria for establishing realistic and appropriate parameters of the classification scheme. Studies of the discomfort of various postures will be used to help define the various classes of posture.

CONCLUSION

A Stat-tablet has been designed for analyzing posture data recorded by an electrogoniometer for different occupations. It categorizes postures into 4 posture classes and 2-time classes. The Stat-tablet has been used to analyze the postures adopted by sheet rockers.

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Figure 1

	DD	Neutral	Moderate	3D-Mod	Extreme	
Dynamic	Total	275 (4)	3213.5 (45)	1688.5 (24)	1135.5 (16)	6312.5(88)
	Mean	1.0	0.9	0.8	0.8	
	Med	1.0	1.0	1.0	1.0	
Static	Total	54.5 (1)	437 (6)	267.5 (3)	97.5 (1)	856.5(12)
	Mean	9.1	9.5	9.2	7.5	
	Med	9	9.5	8.7	7.0	
	Total	329.5 (5)	3050.5 (51)	1956 (27)	1233 (17)	Total= 7169 (100%)

	JH	Neutral	Moderate	3D-Mod	Extreme	
Dynamic	Total	756 (10)	4070 (51)	671 (9)	1128 (16)	6625(92)
	Mean	0.9	0.9	0.8	0.9	
	Med	1.0	1.0	1.0	1.0	
Static	Total	26 (0.4)	361 (5)	43 (0.6)	127 (2)	557(8)
	Mean	8.7	9.3	8.6	8.5	
	Med	9	10.2	10.5	7.5	
	Total	782 (11)	4431 (62)	714 (10)	1255 (17)	Total= 7182 (100%)

	IC	Neutral	Moderate	3D-Mod	Extreme	
Dynamic	Total	974 (14)	4018.5 (61)	576.5 (11)	220 (3)	5736(88)
	Mean	1.1	0.9	0.9	1.0	
	Med	1.5	1.0	1.0	1.5	
Static	Total	151 (2)	524 (8)	46.5 (0.5)	29 (0.5)	750.5(12)
	Mean	7.9	8.7	7.6	7.3	
	Med	7.6	8.6	7.5	8.5	
	Total	1075 (16)	4542.5 (70)	623 (10)	249 (4)	Total=6489.5 (100%)

	GW	Neutral	Moderate	3D-Mod	Extreme	
Dynamic	Total	446 (7)	3428.5 (52)	829 (13)	1093.5 (17)	5797(89)
	Mean	0.8	0.8	0.8	0.8	
	Med	1.0	1.0	1.0	1.0	
Static	Total	26.5 (0.4)	541.5 (8)	41.5 (0.6)	99.5 (2.0)	709(11)
	Mean	8.8	10.8	10.4	11.1	
	Med	9	10.6	24.0	11.6	
	Total	472.5 (8)	3970 (61)	870.5 (13)	1193 (18)	Total= 6505 (100%)

Development of Technique to Analyze the Postures Adopted by Workers.. A Practical Application of the Goniometer

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ABSTRACT

A technique has been developed to analyze the postures adopted by workers using an electrogoniometer. It categorizes postures into four posture classes and two time classes. The Stat-tablet described here has been used to analyze the postures adopted by sheetrockers.

INTRODUCTION

Snook (1978) reported that 20% of all injuries due to manual material handling could be prevented and savings realized if workplaces were designed to minimize stresses on the back. Poor postures during lifting have been shown to contribute to spinal load (Pauly 1966, Tichauer 1973). The association between awkward work postures and the development of musculoskeletal disorders has been widely documented (Corlett & Bishop, 1976, Magora 1972, Tichauer 1978, Van Wely 1970). Colombini et al. (1985) describe tolerable working postures as a) those which do not involve feelings of short term discomfort and b) those which do not cause long-term morpho-functional complaints.

Perusal of the literature indicates that there is a dearth of quantifiable data to describe Colombini's definition of tolerable working postures. Physiological test books i.e. Kapandji (1974) describe the typical limits of motion of the spinal column for flexion/extension, lateral bend and rotation. But no guidelines have been published for the safe limits of spinal column movement in the workplace.

An electrogoniometer that continuously measures trunk range of motion in the worksite was described in two previous papers (Beynnon et al. 1986 and Weisman et al. 1988). A computer program was developed that can analyze data both spatially and temporally. Data was presented graphically. This paper describes a technique known as a "stat-tablet," which sets limits for adopted postures and enables statistical analysis to be conducted on the collected data. This stat-tablet will eventually be used for analyzing the tolerability of occupations in terms of adopted postures. The data used here describes the postures adopted by sheet rockers.

METHODS

The device and the graphical presentation of the data are fully described in the previous studies. This paper describes the technique for statistical analysis of the data.

As described in the previous studies, data is collected from the goniometer and "binned" into 5 degree bins in a table known as the "Tcube." The Tcube is then used to manipulate the data in order to present it graphically. The Stat-tablet was developed to enable the researcher to compare different workers and different occupations statistically. As described above, it is important to describe working postures both spatially and temporally.

Temporally, postures are classified as being either **dynamic** or **static.** Dynamic postures are empirically defined as those being held for 5 seconds or less. Static postures are similarly defined as being postures held for greater than 5 seconds.
Spatial analysis of the Stat-tablet involves classifying postures into four specific "classes." These classes are:

- **Neutral** - Postures within 5 degrees of the upright posture.
- **Moderate** - Postures in one or two dimensions that are between 5 and 15 degrees from the upright posture.
- **3D Moderate** - Postures that combine all three dimensions that are between 5 and 15 degrees from the upright posture.
- **Extreme** - Postures that are more than 15 degrees in any direction from the upright posture.

The software for the Stat-tablet allows the values, and thus the definitions, of the classes to be changed. The values chosen above have been chosen empirically from information obtained in ergonomic guidelines.

The Stat-tablet is presented as matrix of classes versus temporal information. Therefore cells representing such postures as **Dynamic-Neutral** or **Static-Extreme** are presented. Information on postures in each cell include:

- **Total time in seconds (Percentage)**
- **Mean time**
- **Median time**

Data was collected on 4 men working as sheetrockers on a local construction site. The data was collected for approximately 2 hours for each of the workers.

RESULTS

Figure 1 depicts the Stat-tablets for 4 men working for approximately 2 hours as sheetrockers. All four men spent more than 88% of the time in **Dynamic** postures. The most common individual cell was the **Dynamic-Moderate** cell with the men spending at least 45% of the time in these postures. DD, GW and JH all spent more than 17% of the time in **Extreme** postures, although most of these were **Dynamic.**

DISCUSSION

The results of the Stat-tablet analysis demonstrate that four men performing the same type of work generally experience the same type of postures. Individual tasks performed can explain the specific variations in time spent in various postures.

INPUT/OUTPUT CHARACTERISTICS

The input/output characteristics are measured using a sinusoidal test signal at a fixed frequency and stepped in level from 40 to 95 dB SPL in steps of 5 dB. The frequency of the test signal is chosen to be near the center of each identified processing channel for a multi-channel hearing aid, and 2 kHz is used for a single-channel instrument. The input level, output level, and compression ratio are indicated for each step in the test signal.

ATTACK AND RELEASE TIMES

The test procedure for measuring the attack and release times is based on the ANSI S3.22 standard, but with provision made for analysis near the center frequency of each channel in a multi-channel system. A frequency of 2 kHz is used for a single-channel hearing aid. The test signal starts at a level of 55 dB SPL, jumps to 80 dB SPL, and then returns to 55 dB SPL.

BROADBAND DISTORTION

The ANSI S3.22 distortion measurement recommends total harmonic distortion for input sinusoids at 500, 800, and 1600 Hz. This measurement does not give any indication of how distortion at high frequencies, where most hearing aids have the most gain and therefore most easily go into saturation, will affect the reproduction of low-frequency speech sounds occurring at the same time. A procedure for measuring inter-modulation distortion for a broadband stimulus, on the other hand, can provide information on the amount of distortion that may occur under typical listening conditions.

The distortion test signal is the shaped noise used for the frequency-response measurements, and which is then convolved with a comb filter to create a series of interleaved peaks and valleys. The distortion measurement is based on determining how much energy from the peaks spills over into the valleys. The signal-to-distortion ratio is computed at each valley center frequency by comparing the energy in the adjacent peaks to the energy in the valley. The distortion is then expressed as a function of frequency, and the individual frequency measurements can be combined to give a single figure of merit using a weighting scheme similar to the Articulation Index (Kryter, 1962).

CONCLUSIONS

The set of tests described above gives a much more complete description of a hearing aid than previous tests such as the ANSI S3.22 standard. Existing tests have been modified to give the frequency response, input/output characteristics, and attack and release times. New tests have been developed to determine the type of processing and number of channels and to measure broadband distortion.

The tests are currently being implemented in a personal-computer based test system. This system will allow the comparative measurement of different hearing aids, and is thus the first step towards developing perceptual correlates to the set of physical measurements.

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NEW TESTS OF HEARING-AID PERFORMANCE

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INTRODUCTION

Test procedures often lag behind advances in processing technology. For hearing aids, the standard test procedures (ANSI S3.22, 1982) were originally designed for single-channel hearing aids containing linear or compression (AGC) processing. More complicated processing systems, such as two-channel compression, can not be adequately characterized using the ANSI S3.22 procedures. Thus new tests are needed for the evaluation of the newest generation of hearing aids.

The characterization of a hearing aid requires a series of tests since no one test can give a complete description of how the processing behaves. A suite of tests has been developed using existing test procedures where appropriate and deriving new tests where needed. A total of five tests is used:

1. Frequency response as a function of input level
2. Type of processing and number of channels
3. Input/output characteristics for each channel
4. Attack and release time in each channel
5. Broadband distortion as a function of input level.

The tests are intended for a computer-based system, and will be described in the remainder of this paper.

FREQUENCY RESPONSE

The frequency-response measurements use the shaped Gaussian noise signal described by Burnett, et al (1987). The stimulus consists of white Gaussian noise that has been band-limited to the range 200 Hz to 5 kHz, and then shaped with a one-pole low-pass filter at 900 Hz to give an approximate match to the long-term spectrum of speech. The stimulus is presented at 10-dB increments from 60 to 90 dB SPL, with the frequency-response curve for each presentation level computed from the average power spectrum smoothed in one-third octave bands.

PROCESSING TYPE

The type of processing and the number of processing channels are determined by observing how a bias tone modifies the frequency response of the instrument. To this end, the response of the hearing aid is measured for an excitation consisting of the 60-dB SPL shaped noise combined with an 80-dB SPL swept sinusoid. The response of the instrument to the noise alone and to the swept tone alone are also measured. The purpose of the swept sinusoid is to bias the non-linear processing that may be present in the hearing aid, and the shaped noise is used to determine the frequency response of the instrument.

As the swept tone moves through different frequency regions, it will change the gain and/or frequency response of a hearing aid containing non-linear processing such as AGC. To measure the changes, the hearing-aid response to the swept tone alone is subtracted from the response to the swept tone plus noise. This leaves the shaped-noise output as modified by the processing changes caused by the sweep. The spectrum of this noise is compared to the spectrum of the hearing-aid response to the shaped noise alone; the differences in the spectra indicates the degree of non-linear processing in the hearing aid.

The change in the system frequency response as a function of the sweep frequency identifies the type of processing in the hearing aid. A truly linear instrument will show no change. A single-channel compression instrument, which typically has an AGC control circuit most sensitive to input in the vicinity of 2 kHz, will show no effects when the sweep is below 2 kHz and will then show reduced gain as the sweep nears 2 kHz. Two-channel hearing aids will show different patterns of gain changes as the swept tone is first in one channel and then in the other. Comparing the observed gain pattern with a set of idealized patterns and selecting the best match leads to the identification of the processing in the hearing aid.

repeated administrations of a test typically show substantial learning effects.

Test-retest variability was found to be reasonably low for all four sentence sets. In order to perform the statistical analysis, the percentage scores were transformed to arc sine units (y = 2 arc sine p) in order to stabilize the error variance. The average standard deviation for the four sentence sets was 0.19 arc sine units. This error corresponds to a standard deviation of approximately 7 percentage points for a test score of 80 percent and is comparable to the standard deviation that would be obtained for a binomial distribution of test scores for a test consisting of 16 items. (Note that the number of items in each sentence set was 16. A smaller standard deviation is obtained by combining the scores from the four sentence sets.) The binomial sampling error is commonly used as a lower bound for tests involving percent scores.

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Table 1: Test Scores on Sentence Verification Test

Session	Replication	Test Sentences A	Test Sentences B	Test Sentences C	Control Sentences
1	1	84.9	89.7	92.9	70.0
1	2	80.6	91.9	91.9	65.0
1	3	89.3	95.1	94.8	75.0
1	4	89.7	91.9	94.8	70.0
2	1	75.1	92.9	91.6	72.5
2	2	84.7	94.9	96.1	71.3
2	3	93.5	95.1	93.1	78.8
2	4	92.9	89.8	96.1	77.5
3	1	80.4	94.8	93.1	73.8
3	2	92.2	96.9	96.4	78.8
3	3	93.5	93.3	95.4	86.3
3	4	93.6	96.0	95.9	82.5

A Sentence Test for Hearing Aid Evaluation

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Abstract

It is common practice to evaluate the intelligibility of amplified speech using phonetically balanced word lists. Most speech communication, however, involves much longer units of speech, such as sentences or continuous discourse. Sentence test materials have much greater face validity than phonetically balanced word lists, but are seldom used because of poor test-retest variability and substantial learning effects on repeated administration of the test. In order to address this problem, a sentence test has been developed that has small test-retest variability and low learning effects.

Structure of Test

The underlying reationale of the test was to use the same set of words in different word orders or using different syntactic forms so as to change the meaning. For example, consider the following five sentences:

Cats often chase mice.
Mice often chase cats.
Cats are chased by mice.
Mice do not chase cats.
Mice are not chased by cats.

In each case, essentially the same set of words has been used and these words may be familiar to the listener. However, the meaning of each statement depends on the combination of word order, syntax, and the vocabulary used.

The method of testing is to present the sentences in random order to the subject via a hearing aid, or any other speech communication system that is to be evaluated. The subject responds after each sentence by indicating whether the statement was true or false.

Four sets of sixteen sentences were prepared. The first three sets of sentences, referred to as the test sentences, were structured along the lines described above. Each of these sets of sentences used a different vocabulary, the vocabulary within a set being essentially the same for all sentences. The fourth set of sentences, referred to as the control sentences, were similar in format in that they required a true/false response, but the in this case vocabulary in each sentence was quite different; i.e., the structure described above was not used.

Experimental Evaluation

The four sets of sentences were combined in random order and presented to five normal hearing subjects. The signal level was reduced systematically, so as to reduce the percentage of correct responses below 100 percent. The test was then administered twelve times at this level, four replications in each of three test sessions. The test sessions took place on different days.

The results of the experiment are summarized in Table 1 below. The data have been averaged over subjects. Each entry in the table is percent correct.

A repeated measures analysis of variance (repeated over subjects) did not show significant learning effects for the test sentences, except for Sentence Set A which showed a significant replication effect within test sessions. This appeared to be an adaptation effect in that the first measurement in each test session showed a lower than average score, although there was no significant change in average test score between test sessions. The control sentences, in contrast, showed significant learning effects both within and between test sessions. The magnitude of the learning effect, however, was less than anticipated. With conventional sentence test materials,

3) Within the range of 85 - 105 dBA, sound characteristic is more important than sound pressure for recognizability.

Based upon test results, a placement and cost analysis were performed. These analyses showed that:

4) For standard room configurations, there is a need for one signal appliance in each room in order to achieve either visual signal coverage or audible signal coverage at 95 dBA.

5) It costs approximately the same to install audible signals to achieve 95 dBA minimum sound pressure in a building as to install visual signals.

Discussion

Visual signals have the advantage of being able to alert persons who are profoundly deaf, and cannot hear an audible alarm signal of even 95 dBA. They also have the advantage of providing a second stimulus, i.e., a reinforcement, for the general population. Visual signals as determined by the Visual Signals Project are appropriate for use as signaling devices. When choosing auditory alarms, devices with periodic variations, or three or four clear tones are more effective than a steady sound.

More research is needed to distinguish the relative difference between periodicity and tone characteristics. Further research could also address the needs of persons with severe losses of both hearing and vision faculties.

Acknowledgements

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Auditory Alarms Project

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Introduction

The purpose of the Auditory Alarms Project was to establish the potential effectiveness of audible fire alarm signals with respect to persons with mild to severe hearing impairments. The principal method for doing so was to conduct tests of a selection of fire alarm signals by persons with partial hearing loss. The results of testing were used to construct application scenarios for estimating the cost of providing more effective audible alarms. Conclusions and recommendations were derived from the results of testing, of cost analysis, and from a consideration of the results of previous research into visual signals.

Methodology

The objective of testing was to learn if people with a typical range of hearing impairments responded more or less effectively to alarm signals with different sound characteristics such as frequency, number of tones, variability of tone, and amplitude. Rather than test each of these variables independently, the research team found it more practical to test commercially available alarm devices which incorporated differences in these variables. Two dependent variables were measured: recognition of a sound as an alarm signal and time to respond. Six commercially available fire alarm signals were recorded as were four non-alarm sounds, as shown below:

Alarms:	Non-alarm sounds:
Mechanical:	
Vibrating Bell	telephone
Single Stroke Bell	door bell
Horn	automobile horn
Smoke Detector	jet aircraft
Electronic:	
Fast Whoop	
High - Low	

The presentation of the alarm sounds was fully automated using a HyperCard program running on a Macintosh SE computer. The alarms were presented to the subjects at three sound pressure levels: 85 dBA, 95 dBA, and 105 dBA.

Sixty subjects participated in the testing. Fifty three of the subjects had mild to severe hearing losses. Seven had hearing losses in the profound range.

Testing was in three stages. Test A was a paired comparison test which had the subject decide which of two sounds was "more like an alarm." All ten sounds were presented in all possible combinations within each sound pressure level.

Test B required the subject to decide if each sound was an alarm signal or not, when presented at each intensity level. Test C was the same as Test B, with reverberation added.

Results

Testing concluded that:

1) Sound characteristics did make a difference in hearing impaired subjects' response to an alarm signal. An observation of test results led to two hypotheses:

a) An alarm signal consisting of three or four clear tones is more effective than signals with a single tone, reverberating tones, or broad spectrum tones.

b) An alarm signal with two-phase, periodic variations is more effective than a steady sound.

2) Louder alarms are more effective, especially up to about 95 dBA in sound pressure.

ers together to form a parallel computation network inside of a PC. We also use a transputer with a special graphics co-processor called a Videoputer to animate our edge-detected images. (Videoputer is a trademark of Microway, Inc. Transputer is a trademark of INMOS Corp.)

For our tests, we use a system of five transputers, one of which is the Videoputer. The Videoputer was set up as the root, or "master" transputer; the others are the "worker" transputers.

In order to parallelize the image-processing software, we noted that we could concurrently perform edge-detection on different portions of the image. We therefore developed software so that the "master" transputer reads in a video image and then splits it into various packets. These packets are then sent to the "worker" transputers, which perform the edge-detection and contouring on whatever portion of the image they receive. As soon as a "worker" finishes a portion of the image, it sends the results back to the "master" and then gets another packet of that image from the "master". It does not matter which portion of the image any particular "worker" receives- it needs only to find any edges/contours in its own particular packet.

In order to achieve further speed-up, the "master" itself has two separate tasks running concurrently- one task to split the image into packets for the "workers", the other to receive the results as they come in.

IMPROVING THE ALGORITHM

We have modified Pearson's 5x5 valley-detection operator, eliminating checks for determining if a valley is absolute and instead just checking for relative valleys. Not only does this save some processing time, but we feel that the resulting images are more intelligible.

We have also put in initial checks to see if a pixel is below a certain gray-scale threshold. If so, we deem that pixel to be background, and do not look for any edges. Since our test images have been between 40% to 60% background, this represents a significant savings in computation.

RESULTS

The result of using transputers has been spectacular. Using just a PC, it takes anywhere from 4 to 8 seconds to edge-detect and contour a single image. With transputers, we have cut the processing time to 0.13 to 0.15 seconds per image. In other words, we can edge-detect and contour 7 to 8 images per second. We are highly encouraged by these results, and feel that with a little more effort we can achieve a processing time of 0.10 seconds, or 10 frames per second. Some preliminary results suggest that signed-speech will still be intelligible at this rate. Formal intelligibility studies are being conducted by Gallaudet University.

REMAINING AREAS OF STUDY

One problem that remains in using transputers is getting an image to the "master" quickly enough. There are vendors developing frame-grabbers for transputers that we feel should solve this problem.

We are also pursuing the use of ISDN technology to widen the telephone bandwidth available to send animated images over the phone lines.

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A Real-Time Visual Telephone for the Deaf

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ABSTRACT

This paper describes the techniques and new technologies used in the development of a real-time visual telephone for deaf individuals. This telephone will be able to transmit, over ordinary phone lines, animated images of a person communicating via sign-language.

INTRODUCTION

Current Telephone Devices for the Deaf (TDD's), allow communication between two parties at a rate of 1/4 to 1/3 of speech. Clearly, a device is needed so that deaf individuals may communicate over the phone at the same rate as the hearing world. Since a primary form of communication for deaf individuals is visual sign-language, a way must be developed to transmit sign-language over our existing, ordinary phone lines.

PREVIOUS WORK

In order to communicate visually over the telephone we need to be able to compress the vast amount of data in a video image so that it may be intelligibly represented on the recieving end of the phone. Previous work by Poizner et al. (1981) have shown how point light displays can be used to represent the upper extremities used in American Sign Linguage (ASL); Tartter and Knowlton (1981) extended this to include hand configurations; Foulds (1986) extended this one step further to incorporate facial expressions. At each step, it was shown that signs produced by the animation of the resulting representation of these point-light displays, namely stick-figures, were as intelligible as those produced by the original signer. However, we would like to be able to generate "more human-like" representations of the signer, to give the receiver the impression of actually communicating with another person.

DATA COMPRESSION

The first step in the compression of video image data is to extract those features meaningful in the image. To do that, an edge-detection algorithm is performed on the image. This algorithm will extract features such as the hands, arms, torso, head and face from the image. There are several edge-detection algorithms available- we have chosen the one described by Pearson and Robinson (1985) that uses a 5x5 pixel operator to not only extract the edges from an image, but to further filter those edges to detect those that are valleys. These have been shown to generate clean, crisp images, bringing out facial features in particular.

Once we have generated an edge-detected image of individual points, the next step is to further compress this image representation through contouring- that is, representing these points as lines connected by two end points, and possibly one or two intermediate points. Various techniques may be used here- we are looking into using a simple linear-interpolation technique.

One final technique of data compression is also used. Whereas the resolution of an entire video image may range anywhere from 320x480 pixels to 480x512 pixels, we may not need that large of a resolution to effect intelligible images. Pearson (1981) and Sperling (1981) have shown that a resolution of approximately 100 x 100 pixels, used for television closed-captioning, provides nearly 100% intelligibility. We feel that an image (in our case, 480 x 512 pixels) may be reduced to a 256 x 256 representation without an appreciative loss of intelligibility.

TIME CONSTRAINTS

Even though the techniques for compressing a video image are well-known and easy to program, we still need to be able to perform the image reduction, edge-detection and contouring quickly enough so that real-time conversation may take place. By real-time, we mean processing 30 frames/second. Unfortunately, personal-computers cannot even begin to approach the necessary speed. One way to achieve the speed necessary is to lower the frame-rate and interpolating, if necessary, the missing intermediate frames. Foulds (1986) showed experimentally that using Bezier interpolated stick-figures at 6 frames/second resulted in no significant loss of intelligibility. However, frame interpolation does increase computation time. Images animated at higher frame-rates also look more natural, closer to the natural movements of the signer.

Even with lowering the frame rate, PC's remain at least one order of magnitude away in the computation speed necessary to compress video images in real-time.

THE USE OF TRANSPUTERS

In order to achieve real-time image processing, we are using parallel computation techniques. The hardware used for this is called a transputer, which is an independent processor and memory that may be added to a PC. Transputers have the added feature of four communication links, so that you may link any number of transputexperiment are summarized in the table below. All of the children showed improved scores on an articulation test administered before and after training. For two of the children, the improvement was statistically significant. Most of the measured improvement involved sounds for which the palatograph was used.

The results of the pilot study showed that improved speech production is possible using a computerized speech training system including a palatograph. The investigation also revealed an important need to develop speech training curricula for use with modern speech training aids.

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Percentage of Correct Productions

Subject	Pre-Training	Post-Training	Significance Level
1	56	61	----
2	38	64	p <.01
3	37	43	----
4	28	47	p <.05
5	24	35	----

Figure 1

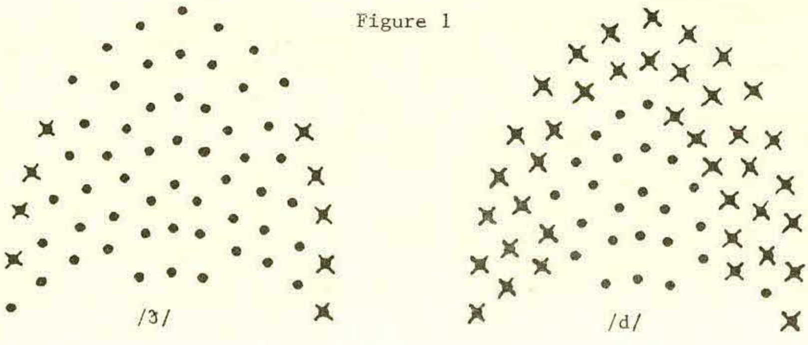
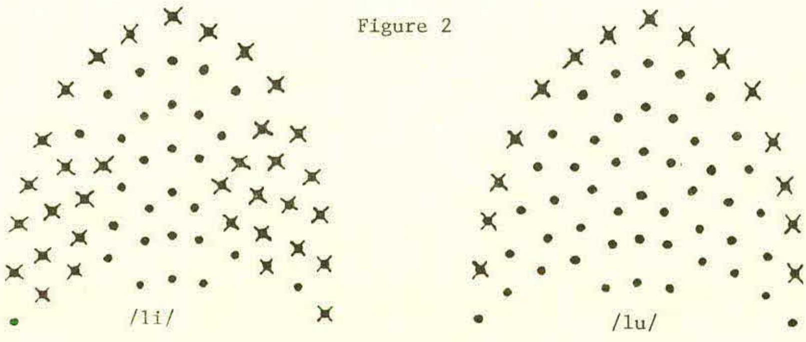


Figure 2



A Speech Training Aid for Deaf Persons Using a Palatographic Display

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Abstract

Visual displays have been found to be useful in teaching speech to deaf students. Experimental evaluations of speech training aids have shown good results with various displays showing the prosodic characteristics of speech, such as displays of voice pitch or temporal variations in speech level. Displays of articulatory movements have not been as successful, largely because of the difficulty in providing reliable displays of articulatory features. The palatograph offers a means for providing a reliable indication of tongue placement in speech. A speech training system which includes a palatographic display is currently being evaluated.

Background

The Matsushita speech training system consists of several sensors for monitoring speech production. These include a laryngeal transducer, a nasal transducer, an air-flow monitor, a voice-activated microphone, and an artificial palate for monitoring tongue placement. The system is computerized and allows the speech teacher to display on a video screen any of the speech parameters being monitored. The parameters may be displayed singly or in combination with other parameters. Digital recordings of the student's speech and associated parameter values can be stored conveniently for purposes of record keeping and future analysis.

Of particular interest in the current investigation was the palatographic display. An artificial palate, similar to an orthodontic retainer, is placed in the mouth. The artificial palate is very thin and rests against the hard palate (the front upper surface of the oral cavity). The adult size artificial palate contains 63 tiny sensors evenly distributed across the surface of the device. A smaller, child size artificial palate contains 52 sensors.

Palatographic Displays

When contact is made between the tongue and the artificial palate during the production of a specific speech sound, a pattern of illuminated dots appears on the video screen. This dot pattern, referred to as a palatogram, identifies which sensors have been activated, thereby providing visual feedback of tongue placement.

Figure 1 shows typical palatograms for the consonants /ð/, as in <u>the</u>, and /d/, as in <u>do</u>. The substitution of /d/ for /ð/ is one of the most common articulatory substitutions in the speech of deaf children. The difference between these two sounds in terms of tongue placement is clearly evident from the diagram.

Figure 2 shows the effects of co-articulation on tongue placement. Palatograms for the consonant /l/ are shown. The left-hand side of the diagram shows tongue placement when /l/ precedes the vowel /i/, as in the word <u>lee</u>. The right-hand side shows the tongue placement for /l/ preceding the vowel /u/, as in <u>loo</u>. Deaf children have great difficulty in producing sounds in context, largely because of the complexities of co-articulation in normal speech. The palatogram provides a clear illustration of these effects and has been found to be useful for both training and evaluation.

Results of a Pilot Study

An experimental evaluation of the computerized speech training system using the palatograph is currently in progress. In a pilot study, five profoundly deaf children were trained on the system over a six week period. The results of the

Research Council) based on the now-defunct TSI Mini Speech Board provides a ready-made set of applications for the new board, since the simple non-microprocessor based interfacing used by the TSI board is compatible with the Nattering RAM. The design is freely available to manufacturers and do-it-yourselfers for incorporation into a wide variety of devices. Full details of the circuit are available [3], and a printed circuit board version should appear shortly.

CONCLUSION

The Nattering RAM speech board appears most useful as an "OEM"-type component for adapting a wide variety of devices and instruments for use by the blind. Its advantages include low cost, simple interfacing, user programmability, and the fact that none of the component parts will become obsolete in the foreseeable future.

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THE NATTERING RAM: A SIXTEEN-WORD, FIELD-RECORDABLE SPEECH BOARD

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ABSTRACT

In the field of talking instruments for the blind, there is a need for a simple user-recorded speech module that is not dependent on microprocessor and speech chip sets which are frequently changed or dropped from production. The "Nattering RAM" is such a device. It is a general-purpose, user-recordable, limited-vocabulary, addressable speech board which uses entirely basic and "generic" chips in its construction.

INTRODUCTION: THE PROBLEM

The product life of speech boards and chip sets has been shorter than that of talking devices for the blind. With the demise of both the TSI "Mini Speech Board" and the National Semiconductor "Digitalker" chip set, some useful talking meters and calculators have disappeared with them. It would therefore be desirable to have a speech board which does not depend on any speech chip, delta modulation chip, or microprocessor, but uses only the basic "generic" components and circuit building blocks which will always be available.

In contrast to the Nattering RAM, a generic voice module (using a commercial synthesizer chip) is made by AFB and marketed as the GVM [1]. This is an add-on device which is very useful for adapting certain commercial products that have a suitable output to drive it; however, its application is limited to a particular class of special modification. A more general approach would be useful for other applications.

Accordingly, we have designed and tested a speech board (the "Nattering RAM") which fulfills these criteria.

NATTERING RAM IMPLEMENTATION

A standard 32k-byte RAM is used to store digitized speech which is recorded by the user via a microphone and a delta modulator composed of an LM324 quad op-amp, an LM311 comparator, and a CD4013 flip-flop. The resulting bit stream is converted from serial to parallel form by a shift register, prior to storage in the RAM. Storage in the RAM is maintained by a backup battery that can be replaced by the user every three years or so. In playback, the data are converted back to serial form, demodulated by a simple integrator, and fed to a loudspeaker via an LM386 power amplifier. Thus, no special or proprietary components are needed; all can be obtained "off-the-shelf" and have a long history of stable supply and decreasing cost. Although approximately fourteen chips are needed, most cost well under a dollar each even in unit quantities, and total costs are very low.

Features built into the device include the ability to program it in the field, in any language. The sixteen addressable messages can be digits or any other desired information. The input addresses can be made to follow a logical order; for example, the words "zero" through "nine" can be organized in the binary sequence of 0000 through 1001, greatly simplifying direct interfacing to BCD data. Sampling frequency (governing message length and speech quality) can be varied from 16 to 60kHz. A DIP switch allows user-selection of each address to be recorded. A "pitch-shift" input allows the user to accentuate words or present decimal digits in a different pitch than more significant ones, thereby eliminating the need for the word "point" to indicate the decimal point (this also simplifies addressing).

A most important feature, vital for practical use by the blind [2], is the "shut-up" or "abort" input, which enables the user to immediately truncate the speech stream.

APPLICATIONS

To date, we have interfaced the Nattering RAM to the National ADC3511 voltmeter chip via a circuit designed by Susan Fowle; the first applications were a Spanish language talking blood pressure meter and an "any-language" voltmeter. A talking clock based on this technology is about to become commercially available.

The above applications have been successfully tested, and others are being explored. The availability of many talking instrument circuit designs (e.g., those available from the Canadian National a phone call, dial a number (by speaking the name of the person to call), record a message, or play back that message by spoken commands.

Like a sophisticated answering machine IIVA allows the user to do some remote functions. A user can call from any place and play back his messages, record new messages, find a certain message, or erase any message.

Given the increasing importance and performance capabilities of computers today, the ability to operate one is very essential. IIVA helps physically disabled individuals who has limited speech capability, to operate any software that could normally operate on an IBM personal Computer.

DISCUSSION

IIVA is an intelligent voice-based software interface for computer access. IIVA incorporates voice-recognition and telephone management and provides a friendly human-machine interface to a wide range of application software programs and electrically controlled devices that are integrated in a workstation for the physically disabled. IIVA also contains the necessary software programs which integrate the various subsystems and devices that comprise the workstation.

IIVA can be used either by single keystroke commands selected from user-friendly menus, or by simple voice commands in place of the keyboard.

IIVA can play a role, as a versatile user-friendly access program, in providing disabled persons with the ability to control their environment and perform a range of computer-based functions. In addition, IIVA contributes to increased ability of disabled individuals to communicate.

ACKNOWLEDGEMENTS

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IIVA: AN INTELLIGENT INTERFACE FOR VOICE APPLICATIONS

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ABSTRACT

Voice technology has made remarkable progress during the last few years and research has demonstrated the importance of voice technology in rehabilitation engineering [1,2,3]. This paper describes the development of an intelligent interface for voice applications (IIVA) which enables a physically disabled to use software and hardware devices installed on a workstation for physically disabled individuals via spoken commands. IIVA is an on-line system; that is, at any time, the user can train, test and recognize any word (command) that might be needed while operating the workstation.

METHODS

IIVA operates on a workstation designed for physically disabled individuals. IIVA is designed as a "front-end" or "user-interface" for access to the computer integrated workstation environment. It also integrates the various software programs and hardware subsystems that comprise the workstation. Some of these subsystems include a robot, a telephone, an automatic door opener, and a system to turn lights and appliances on and off [4].

An IBM Personal Computer AT is used to control the workstation. This computer was used since it provides the standard AT-bus with the necessary serial and parallel ports to accommodate the voice recognition and phone management add-on boards.

Assembly language is used to make the IIVA a memory resident system. Memory residence provides on-line access to IIVA while the user is running an application on the workstation.

Programming for IIVA is accomplished using the Clipper programming language interfaced with the programming language C. Clipper is used to write the system's menus and help screens. When the user selects certain functions from the IIVA menu, IIVA's Clipper-based routines call certain C functions to perform the voice and telephone-based applications.

IIVA is menu-based to provide easy access and understanding for the user. Such an interface makes IIVA user-friendly and efficient in terms of speed of operation.

For voice recognition, IIVA uses the VoiceScribe-1000 Plus board developed by Dragon Systems [5]. VoiceScribe provides the voice command capability for IIVA and enables the user to train, test and recognize any phrase need to be recognized.

IIVA's phone management program uses the Watson board developed by Natural Microsystems [6]. By integrating voice recognition and phone management functions in a single application, with a database, IIVA allows an individual to simply speak the name of the person to be called, and the computer will dial the number, and if requested will leave a message. IIVA also can be used as an intelligent telephone answering and messaging service which can record, playback, store, access and forward messages with simple voice commands.

RESULTS

A prototype of the system is currently has been developed which can perform several functions.

At any time, <u>during operation</u>, IIVA can be easily run by using a "hot key" (SHIFT+M) to train, test and recognize a certain command or a set of commands. Once trained, a command or a set of commands can be used (recognized) or updated at any time.

IIVA enables an individual to answer

Examples of control and status feedback supplied through the synthesizer would include: telling the user (on request) what document they are in, what programs are currently running, what documents are opened under each program, where they are in a document, etc.

Examples of synthesizer use in reading information from the screen would include reading: the word currently under the mouse, everything that they touch with the mouse, everything from the current point on down the page until they stop it, the whole line, the whole paragraph, the whole page, etc. The system will also have the ability to recognize commonly used icons and automatically read to the user a word or phrase that the user associates with that icon. A tone accompanies the icon's name so that the blind user can distinguish between icon names and regular text on the screen.

Speech Recognition or Tactile Tablet Commands

Commands can be given to the blind user's interface and to the computer itself in two ways. First, they can be given as vocal commands which are picked up by the speech recognition system and fed to the interface or computer. The command "Windows" for example would give the user a list of the windows currently open. The voice commands would also allow the individual complete access to the document manipulations, such as "Screen Up," "Screen Down," "Position (in document)," etc. Most of these are commands that are traditionally carried out using the mouse to click on or drag various visual symbols, scroll bars, etc., on the screen. With this system, the same functions would be achieved using a verbal rather than a visual metaphor. For deaf-blind users, a dynamic braille display can be substituted for the speech synthesizer. For selected applications, it may also be preferred to the voice output by blind users.

In some cases, vocal control of the computer is not desirable or effective. This may include environments where constant talking is not allowed, or situations where the speech recognition unit is not able to accurately recognize an individual's speech patterns or accent, or where the individual is not able to speak, such as an individual who is deaf-blind. In addition, once a system is mastered, quick manipulations of the hand can often be faster than vocal manipulations. The system therefore has the ability to be completely controlled from a virtual keypad on the tactile tablet. The virtual control keypads are located at the bottom, left and top of the touch tablet (see Figure 2). These buttons can be felt by the individual using the tactile mouse. Whenever they enter a button, its name is automatically spoken (quickly) up to them. If they enter another button while the computer is still reading the last button, it immediately stops and switches to reading the new button. Because the buttons exist in software, their size, shape, and number can be changed to meet the specific needs of the user. Their functions can also be dynamically changed to meet the needs of different applications. Because the button titles are read whenever they are entered, it is easy for a blind person to determine where they are and whether they are over the desired button before they click the mouse.

Basic principle in the design of the interface include:

Direct presentation of information in nonvisual form

Allow as much direct control as possible by the user

Utilize natural spatial perception systems and experiences of users

Use the best aspects of several presentation systems simultaneously to create synergistic benefits

Provide a simple cued mode of operation to allow the system to be used quickly and with minimal training

Provide faster, direct control shortcuts for more experienced user and make these intuitive as well

Make provisions for cooperative programs

Wherever possible, use identification and verbal presentation of common icons and graphic images, rather than forcing exploratory interpretation

Minimize the need for slow graphic interpretation by maximizing verbalization of command structures

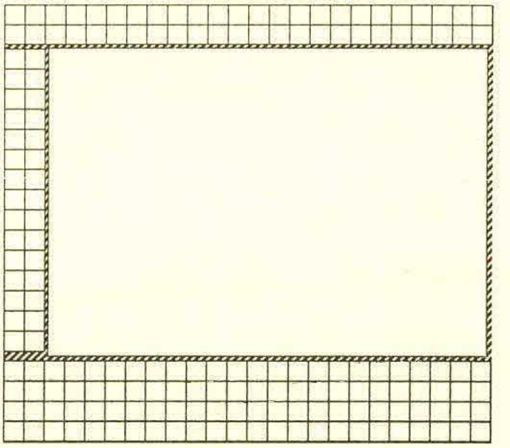

Figure 2

SUMMARY

This paper describes a nonvisual computer interface which is compatible with the visual metaphor operating systems now proliferating. The system is based upon two basic principles. The first principle is that of bypassing the visual metaphor wherever possible and presenting the information to the blind individual in the most effective form (tactile, audio, haptic), while providing tools to facilitate the direct interpretation of the visual image where that is optimum or desired. Secondly, the system is designed to be as intuitive and self-explanatory as possible while at the same time including more powerful shortcuts for more intense or experienced users. The overall objective is to create a system which not only provides access to the computers and programs, but to do so in such a way that the user who is bind can operate the computer and the programs at a rate which is more comparable to use by their sighted peers (except for graphic-intensive applications).

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SYSTEMS 3 - AN INTERFACE TO GRAPHIC COMPUTERS FOR BLIND USERS

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ABSTRACT

A nonvisual computer interface is proposed to allow access to standard, graphics-based computers and software (e.g., Macintosh) by persons who are blind. The system uses a five-layer access approach which seeks to optimize access to cooperating software, and provide access to non-cooperative software as well. The system is based upon the premise that it is more efficient and effective to present information to blind persons using nonvisual metaphors than to have them try to interpret information presented in a visual, graphic format. The proposed system operates using verbal and spatial/tactile presentation of information, and only relies on interpretation of the actual graphic image when absolutely necessary (or desired by the blind user). The system incorporates speech output, speech input (optional), a full-page virtual tactile display with single-pixel resolution, and an optional braille display. These displays are used to present and manipulate information in verbal, tactile, or haptic form (or combinations thereof) in order to take advantage of the strengths of these different sensory channels for different types of information.

OVERVIEW OF THE PROPOSED SYSTEM

There are four basic components to the overall system:

- a full-page virtual tactile tablet;
- a voice synthesizer;
- a speech recognition system (optional); and
- a dynamic braille display (optional - especially useful for deaf-blind users).

The Virtual Tactile Tablet

The virtual tactile tablet consists of a standard graphics tablet with a special tactile mouse. This mouse has a small array of stimulators (5 columns of 20 pins) on 0.2 x 0.1" centers. This tactile array is mounted directly above the "virtual ball" of the mouse. As the individual moves the mouse around on the tablet, they would feel on their fingertip a raised, vibrating representation of the image on the screen at that point. The result would be similar to having a full-page raised tactile image of the screen, which the individual could feel with a single fingertip. The mouse chosen for this system also provides information as to the angle of the mouse, so that the blind individual can easily move about the tablet without having to hold the mouse perfectly vertical (Figure 1).

The tactile tablet is used in a number of ways within the system, usually in combination with the speech synthesizer. The tactile tablet is used for:

General orientation and layout of the document;

To direct the screen reading (via speech synthesizer feature) to the particular lines or words that the individual is interested in for spot reading;

To feel the particular shape of images on the screen (e.g., follow a line on a graph, feel a bar chart, etc.); and

To interpret simple graphic images with captions or words on them by feeling the image and having any words read aloud.

(Practiced Optacon users may be able to directly read the letters off of the screen using the tactile array, although it would be slower than using the 300+ words/minute speech synthesizer).

When the user is orienting himself to the layout of a large page of text and numbers, a tonal feature is also available which emits a different tone for letters, numbers, or graphics information, as the individual moves their hand about screen. Using a combination of the tones and the tactile image of the screen, the individual can quickly get a sense for the overall layout of the page, as well as the location of columns, words, numbers, and graphic elements on the page. The individual can then leave ToneTouch mode and proceed to explore the individual elements on the page in more detail.

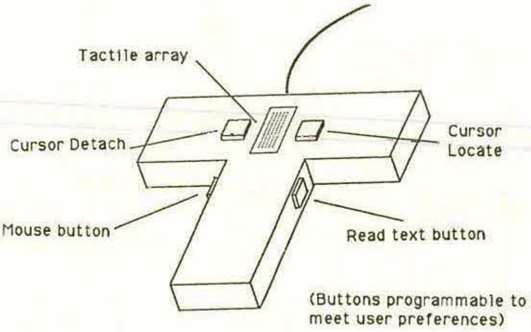


Figure 1:
The Visual Tactile Tablet -
Close-up of the tactile mouse
(the "wings" house the tactile actuators)

Voice Synthesizer Functions

The voice synthesizer provides two primary functions. First, it provides information to the user regarding the commands available or status of the computer. Second, it reads text, icons, and other information from the screen to the user. In both cases, the information read to the user is in direct response to an action or request from the user. Except for telling the user that an "alert box" has suddenly appeared on the screen, the synthesizer does little spontaneous talking that has not been directed by the user.

Gold Standard

		Spur	Yes	No
Computer	Spur	39	6	6
	Yes	8	27	0
	No	11	0	30

Computer vs Gold standard (table 1),1st session

Gold Standard

		Spur	Yes	No
Computer	Spur	16	0	2
	Yes	12	48	2
	No	9	0	56

Computer vs Gold standard (table 2),2nd session

Gold standard

		Spur	Yes	No	'C'	'L'	'W'
Computer	Spur	55	14	1	8	0	13
	Yes	28	12	0	0	0	0
	No	8	0	0	0	0	0
	'C'	1	0	0	13	0	0
	'L'	2	0	0	0	0	0
	'W'	6	5	0	0	0	9

Confusion matrix of performance (table 3)

Discussion

Classifying gestures into simple 'yes', 'no', and spurious classes is possible although there is certainly scope for improvements in the recognition rate.

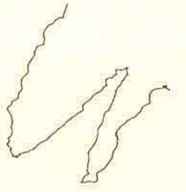
Discrimination over a wider range of gesture classes results in much lower recognition success. The predominant problem is that the gestures are widely varying. Thus of the 3 examples of a 'W' gesture shown in figures 1,2 and 3 only the third example was accepted by the hidden Markov models as a valid 'W'. The first two gestures were designated spurious although they had the highest probability of being a 'W'. Two factors are responsible for weakness of the gesture classification technique when used with more than 2 movement gestures. The first is that the measurements are neither tolerant of scale variations nor encapsulate information used by a human observer to discriminate gestures. Thus a measure of curvature may be a better one to use when assigning a symbol sequence to a gesture rather than the crude velocity estimate. The second weakness is representing a variable gesture in a hidden Markov model. If there is a large variation in the symbol sequence a Markov model will need more states and more data to represent it correctly. Using multiple hidden Markov models to represent a single gesture is one possible solution but some care would be needed in the training process.

Conclusion

Research on controlling a computer with physical gestures is insufficiently advanced to draw any conclusions about its efficacy, however as techniques improve and computers become more powerful we may recognise a potential in this possibility.

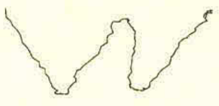
Our research was founded on the belief that similar communication modes could be applied to both interpersonal communication and computer interfacing. Several of the individuals involved in this study have accompanied head gestures with voiced utterance and this information can and should be used in future work (when it is available).

Although controlling an application program with 6 gestures resulted in a low recognition rate it was still possible to complete the task. On the understanding that gestures would be misrecognised facilities were added to allow errors to be corrected. Further it was possible after a gesture to realign the cursor and the persons line of sight and ensure accurate selection from a menu or of a graphics object.



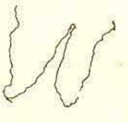
Spur. P('W') = e^{-251} c.f. P('C')= e^{-315}

figure 1



Spur. P('W') = e^{-236} cf P('C') = e^{-425}

figure 2



'W'. P('W') = e^{-196}

figure 3

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Computer Recognition of Head Gestures in Cerebral Palsy

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Abstract

We present the results of some clinical trials designed to assess the feasibility of using simple head gestures to control a computer and to measure the performance of the recognition technique. Physical gestures may be a means of alternate computer access for physically disabled people and we present and discuss one method based on hidden Markov models.

Introduction

Much information in human communication is conveyed by gestures ranging in sophistication from an oration to a wink. Equally flow of communication to a computer is conveyed by a combination of gestures in response to information presented by the computer.

Research into hand gestures was given an impetus with the introduction of the DataGlove which Jim Kramer has used to implement a scheme to recognise the gestures in American Sign Language [1]. Similar work is underway in Norway where Martin Brookes is using a novel form of neural network to recognise simple hand movements [2]. Both Brookes and Kramer are studying hand and finger movement unimpaired by physical disability. In contrast Alistair Cairns [3] is looking at the gross arm movements of people with cerebral palsy and in Cambridge we are looking at cerebral palsy head movements.

Method

Our work at Cambridge is based around a Polhemus Isotrak [4] sensor that can be attached to a person's head via a head band. Information from the Polhemus sensor is used to calculate the position of a virtual headstick 1.5 metres long the tip of which can be portrayed as a cursor on a screen. Short timescale statistics are done on the position of this virtual headstick to estimate an approximate magnitude of movement. This magnitude is used to segment the incoming data into gestures and an underlying application program can look for either resting gestures indicative of head pointing, or movement gestures indicative of 'yes', 'no' or similar head movements.

Candidate data for a head pointing gesture is analysed using cursor position and the time in that position. Data that may contain a movement gesture go through a more complex process. Each incoming sample is coded with 6 measurements. These are:-

- the x and y position of the sample with respect to the previous sample.
- the angle β subtended by the previous sample.
- the X and Y position of the sample with respect to an arbitrary datum.
- the angle α subtended by this datum.

The datum point is chosen in this instance to be the start of the gesture.

These measurements represent a set of points in 6 dimensional space and within this space there are a number of cluster points. The Euclidean distance to each cluster point is measured and each sample is given the symbol associating it with the nearest cluster. The position of the cluster points are chosen from analysis of previous data by a technique known as minimisation of the sum of squared distances [5]. This information is presented to a set of hidden Markov models and each model calculates the probability that it could produce this symbol sequence [6]. The model representing the most likely gesture is chosen providing a threshold probability is exceeded.

Experiment design

The subject was a 23 year old, nonvocal, cerebral palsy quadriplegic who has developed a unique mode of communication by spelling out letters with head and eye movements. This gives her a high speed and intelligible primary mode of communication with the people who interact with her on a daily basis. It also indicates that she has good head control over a small range of angular movements.

Two application programs were used to evaluate head gestures. The first program was controlled by two movement gestures, 'yes' (nodding) and 'no' (shaking) head movements. The internal state of the computer was indicated by a combination of graphics and spoken questions.

The second application extended the number of movement gesture classes used for computer control to six based on the movements the subject would normally used for communication. In addition head pointing gestures were used to control some aspects of the graphics and additional menus. Since one gesture was not used in this particular experiment it has been eliminated from the analysis. Feedback of the internal state of the computer was given by a combination of menus, graphics and sounds.

Results

The results presented are derived from data collected on three separate occasions with the opportunity to retrain the hidden Markov models and re-estimate the cluster centres in between. Logged data for each set of results was viewed by two observers and gestures where they both agreed were taken as a gold standard for comparison with the computer's analysis. Data that could not be classified into one of the available gesture classes was counted as spurious (Spur).

Discrimination of Two Gesture Classes A comparison between the computer and the gold standard is given in table 1. From this it is apparent that the computer and the gold standard disagree predominantly in the classification of spurious movements and gestures. However the computer does achieve a success rate of 74% which was sufficient for the user to complete her chosen target during the application without frustration.

Table 2 presents data collected on the second occasion the two gesture application was used. Since data collected during the first session was available the 'no' model was retrained with 34 gestures and the 'yes' model with 36. The cluster points were also redefined but otherwise the recognition configuration remained unchanged. The higher recognition success rate of 83% (shown in table 2) is attributable partly to the increased competence of the user and partly to the improved performance of the hidden Markov models when trained with more data.

Discrimination of Six Gesture Classes A substantially lower recognition rate was achieved when 6 movement gesture classes were used to control a drawing application program even though the Markov models had 6 states, used 12 symbols and were each trained with 22 example gestures. The confusion matrix shown in table 3 indicates the models' difficulty in discriminating between 'yes' and 'W' gestures and in addition many spurious gestures were classified as valid. The overall recognition rate is 51% with reasonable recognition of the 'C' gesture (62%), but poor recognition of the 'W' gesture (41%) and of the 'yes' gesture (39%).

ture which allows the user to control the mouse from the standard keyboard keypad.

The T-TAM is a box measuring 5 1/8" x 1 1/2" x 5 1/4" and weighing approximately 16 ounces. It is controlled by a Texas Instruments TMS370 microprocessor with 8K of external RAM and 48K of external EPROM. It contains circuitry for interfacing with the Apple Desktop Bus and the IBM keyboard and mouse. In addition, it contains circuitry for an RS-232 serial port and a piezo electric speaker.

Input Device Emulation

The primary goal in the development of the T-TAM was to provide a new emulating interface that would support not only the keyboard, but also the mouse, touchpad and future input devices.

To accomplish this, the T-TAM has an RS-232 serial port for accepting input from alternate input devices. Serial RS-232 is used because this is the most commonly available port on current communication aids and has proved suitable in previous implementations of keyboard emulating interfaces.

This serial port accepts ASCII characters in the new General Input Device Emulating Interface (GIDEI) format and translates them into keystrokes and/or mouse activity on the target computer. Keys which have an ASCII representation (such as alphabetic characters) are "typed" by the T-TAM by simply sending to it the corresponding ASCII character. For keys which do not have an ASCII representation (e.g., Page Down, Left Arrow), and for mouse actions, a special sequence of characters is programmed into a selection on the aid and sent to the T-TAM.

Additional commands exist to enable the user to type multiple sequences of keys and key+mouse actions (e.g., shift-click), to change baud rates, and to select different keyboards.

Keyboard Enhancement

While the primary goal of the project was to develop a new emulating interface device, it became evident that with minor design changes, additional accessibility features could be implemented for people who wish to use the standard keyboard. This was accomplished by designing the T-TAM to be functionally in series with the keyboard and mouse. In this fashion, the T-TAM is able to intercept all input device activity. The signals can then be interpreted and modified before sending them on to the computer.

By allowing the T-TAM to intercept the keyboard and mouse signals before they ever reach the computer, it is possible to implement many of the same features that have previously been implemented as software patches to the operating system. These features are StickyKeys, SlowKeys, Auto-Repeat Rate Adjustment, and MouseKeys. The fact that they are implemented in hardware outside of the computer, however, allows these features to be used with all software and all operating systems for the computer.

The StickyKeys feature is a well known keyboard modification that enables the individual who requires one finger typing to type multiple-key sequences. The implementation of this feature in the T-TAM very closely follows the One-Finger software program for IBM computers available from the Trace Center and the StickyKeys feature available in the Easy Access program in the Apple Macintosh operating system.

SlowKeys is used by individuals who often accidentally press unintended keys while attempting to press a desired key. The SlowKeys feature requires the user to hold down a key for a user-adjustable period of time before the key will be sent to the computer. This setting may be saved in EEPROM memory in the microcomputer for later recall by the user after the device has been powered down.

Adjustment of the auto-repeat rate is a feature used by individuals who are unable to accurately control the release of a key. This adjustment allows the user to slow down the rate at which keys will repeat as well as to adjust the delay before a key starts to repeat. It also allows the user to totally deactivate the repeat action of the keyboard.

MouseKeys is a feature useful to individuals who cannot use the standard mouse to operate mouse-driven software, but can still use the standard keyboard either modified or unmodified. It enables the user to control mouse activity from the keypad portion of their keyboard. Cursor keys move the mouse in the corresponding direction. Pressing other keys causes the "locking down" of the mouse button(s) for dragging or highlighting objects.

For individuals with impaired vision, an audible tone is produced whenever the state of a toggle key (num lock, caps lock, scroll lock) has changed.

CONCLUSION

Several advantages exist both to the user and the manufacturer of communication aids with a system incorporating a stand-alone communication aid used with an emulating interface. For the user, this modular design allows a wider selection of communication aids to choose from, a wider selection of computers to access, potentially less costly repairs, and easier updating to support new features. Manufacturers will find that their aids will access a wider variety of computers, less space on the aid will be taken up by multiple connectors for the various computers, and more resources can be devoted to the development of better user interfaces.

The ideal situation for the implementation of the special keyboard enhancement features would be to build them directly into the keyboards. However, due to economic concerns, computer manufacturers are reluctant to do this. The use of the T-TAM to deliver these functions when software solutions do not work provides a bridge until such time arrives as these features are built into all operating systems and/or computer input devices.

At this time, cooperative efforts are underway with manufacturers to transfer the device for commercial production. It is anticipated that the T-TAM will be commercially available from one or more manufacturers by May 1990.

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TRANSPARENT ACCESS INTERFACE FOR APPLE AND IBM COMPUTERS: THE T-TAM

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ABSTRACT

Many advances designed to simplify the use of the computer and to make it more user friendly for able-bodied users have created new barriers for people with physical disabilities (e.g., mouse input, new operating systems). These barriers often times cannot be overcome in a practical sense with software patches. In answer to the need for an effective interface, a new, low-cost hardware keyboard and mouse emulating interface for IBM and Apple computers has been developed. It also implements many keyboard enhancements which work with all operating systems and application programs running on these computers.

INTRODUCTION

The inability of many users to operate standard input devices such as the keyboard and mouse has spurred the development of several software programs that aid the disabled user in accessing popular computer systems. While programs that provide features such as "sticky key" operation and keyboard and mouse emulation are available for many computers, it is becoming more and more difficult to implement these features with third party software patches when new and more powerful operating systems and computers are developed. In addition, not all application programs work with these software patches.

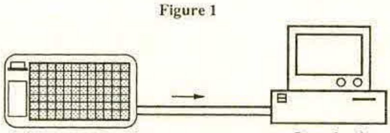
For this reason, many users require a different access avenue is 100% transparent to the operating system and computer. The common approach to providing this avenue is to develop hardware emulation devices which operate outside the computer and use special input methods. These devices typically connect to the computer keyboard and/or mouse ports and exactly mimic the electrical signals of these standard input devices. In this way, the computer, and programs running on the computer, cannot distinguish between the standard input devices and the alternate input devices.

Although the distinction is not always clear cut, most hardware devices which function as described above can be categorized into two groups: the emulating interface and the emulator. (See Fig. 1) The emulating interface is a device which simply provides the "curbcut" to the computer; that is, it connects the alternate input device to the computer system. The emulator, on the other hand, is a device which provides the alternate input device together with the emulating interface as an integrated package.

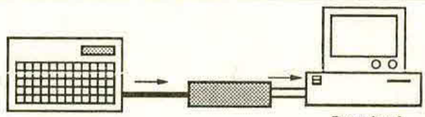
Many communication aids today are not keyboard and mouse emulators by design. It is therefore necessary for these aids to use an emulating interface device to provide the user with access to computers.

The need for emulating interfaces for newer computers, especially computers using mouse input devices, has resulted in the development of the Trace Transparent Access Module (T-TAM). This device provides transparent access to Apple and IBM computers for users of a wide variety of communication aids. In addition to its emulating interface function, features were implemented to provide increased accessibility to these computers by people who simply require keyboard enhancement features.

Figure 1



Some alternate input devices have a built-in capability to emulate a keyboard (or a mouse)



A communication aid can be used to perform the actions of the computer's standard keyboard and mouse, through an emulating interface

DESCRIPTION

The T-TAM was developed to meet the following design goals:

- Supports Apple computers which use the Apple Desktop Bus to connect input devices. (Apple IIGS, Macintosh SE, and Macintosh II's)
- Supports IBM AT and PS/2 computers
- The standard keyboard and mouse should function normally with the device attached and running
- Requires no special software running on the computer
- Requires no special modifications to the computer
- Provides 100% transparency so it will work with all operating systems and application software
- Obtains all power from the computer (no batteries or power supply)

The T-TAM functions in different ways to meet many of the needs of a wide range of users. For individuals who cannot use the standard keyboard or mouse (even with modifications), the T-TAM has a General Input Device Emulating Interface (GIDEI) which allows people to use a wide variety of augmentative communication aids or other special aids in place of the computer keyboard and mouse. In addition, the T-TAM modifies the behavior of the standard keyboard so that people with mild or moderate disabilities may use the standard keyboard directly. For individuals who cannot use the mouse, the T-TAM provides a "mouse key" fea-

POSTURAL STABILITY DURING SITTING IN CHILDREN WITH NEUROLOGICAL DISORDERS

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ABSTRACT
A postural tracking system was used to monitor stability (trunk sway) during static sitting on a horizontal seat base, and to determine the effects of a forward inclined seat on sway of children with cerebral palsy, and children with traumatic head injury. Sitting stability was poorer in children with cerebral palsy than in normal children, while no difference was observed between the normal and head injured population. Changing the seat base angle had no significant effect on trunk stability for either group of neurologically impaired children.

INTRODUCTION
There is little published research specifically addressing postural sway in relation to static sitting balance of normal children and children with neuromuscular disorders. A number of investigations have examined ergonomic and functional concerns of adaptive seating for non-handicapped populations (Bendix, Biering-Sorensen, 1983; Brunswic, 1984; Mandal, 1983). Other studies have addressed the therapeutic benefits of seating for children with neurological disorders (Dilger & Ling, 1986; Nwaobi & Smith, 1986; Stewart & McQuilton, 1987). An earlier study examining the relationship between postural sway and antigravity trunk musculature of children with cerebral palsy (Sochaniwskyj et al, 1990) revealed reduced postural sway and an increase in erector spinae muscle activity in response to sitting on a 10 degree forward-tipped seat base in these children. The present research addressed the need to expand upon the limited existing body of knowledge. The ability to objectively monitor trunk sway as related to sitting will facilitate the evaluation of therapeutic interventions aimed at improving sitting balance in children. Specific goals were to examine the developmental nature of sway on static sitting of normal children, and to examine the effects of horizontal (0°) and forward-inclined (10°) seats on stability of neurologically impaired children.

METHODOLOGY
Subjects
Three groups of children were included in this study: (1) 49 normal children ranging in age from 5 to 15 years, grouped into five groups according to age (see Table 1); (2) eight children with cerebral palsy ranging between 5 and 6 years of age; and (3) seven children with acquired head injury between 13 and 15 years of age. The subjects with cerebral palsy and those with a head injury were classified as mild to moderate, were independent sitters on a flat bench with or without hand support, and were able to ambulate with or without mobility aids.

Instrumentation and Procedure
A tracking system which monitored the coordinates of a specific point in three-dimensional space was used to monitor sway (see Figure 1).

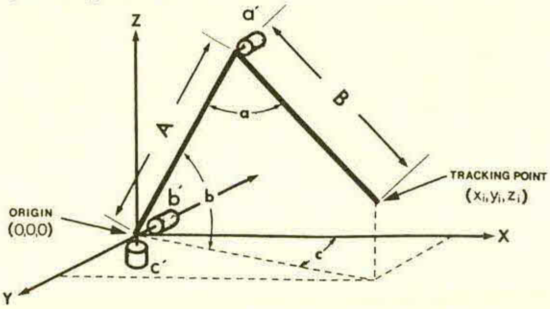

Figure 1. Representation of the 3D tracking system. A and B are 38 cm aluminum rods. Precision potentiometers a', b' and c' measure angles a, b and c respectively. The system origin (0,0,0) is mounted and fixed on an assessment chair.

During the assessment sessions, the children sat on a specially constructed chair with an adjustable seat base angle and foot rests which were positioned to accommodate each subject. This chair did not provide a back support. The seat base pivoted upon an axis parallel to the axis of the hip joints and was located beneath the ischial tuberosities. The "tracking point" of the tracking system was placed over the bony landmark of C7 by means of double sided tape. Subjects were initially instructed to sit still and as upright as possible. Session duration was five minutes, during which the subjects watched an age-appropriate video-taped program. Cartesian coordinate data were collected at 10 Hz by a microcomputer via a multichannel, 12-bit A/D converter. Using the standard deviations (SD) of the x, y, and z coordinates from each five-minute session, the radius (R) of a spherical volume was determined, using:

$$R^2 = SD_x^2 + SD_y^2 + SD_z^2$$

, and was referred to as the "radius of stability".

Group	n	Seat angle [degrees]	Age Range [yrs.]	Age Mean (S)	Radius [cm] Mean (SD)
Normal	6	0	5 - 6	5.5 (0.5)	2.3 (0.79)
	10	0	7 - 8	7.6 (0.5)	1.7 (1.78)
	11	0	9 - 10	9.1 (0.3)	0.9 (0.40)
	10	0	11 - 12	11.2 (0.4)	1.2 (0.61)
	12	0	13 - 15	13.6 (0.8)	1.5 (1.06)
Cerebral palsy	8	0	5 - 6	5.8 (0.4)	3.1 (2.45)
	"	10	"	"	3.5 (2.10)
Head injury	7	0	13 - 15	14.3 (0.7)	1.4 (1.21)
	"	10	"	"	1.8 (1.77)

Table 1. Means and standard deviations of radius of stability (sway) for three groups of subjects.

Incorporating a measurement of the variability of position along all three axes into a single number provided a measurement of gross positional stability. A smaller radius was indicative of greater stability. The cerebral palsy and head injury subjects each attended two sessions, one where they sat on a horizontal seat base, and the other where they were positioned on a seat with a 10 degree forward tilt. The normal subjects were only monitored while they sat on a horizontal surface.

RESULTS

Means and standard deviations of the radii of stability for the three groups are presented in Table 1. A linear regression analysis was conducted for stability versus individual age for the normal group of subjects where:

$$\text{Radius} = 2.164 - 0.097 \times \text{AGE}$$

It is evident that a linear relationship exists between age and radius of stability, implying that sway in static sitting decreases as children get older. Student's t-test analyses performed on the radius of stability data of age-matched normal and neurologically impaired subjects showed no statistical difference, although a greater mean and variability of radius for the group with cerebral palsy was observed, indicating greater instability. The results of the analyses comparing radius of stability between seat base angles for both of the cerebral palsy and head injury groups also revealed no significant differences.

DISCUSSION

The results of this study provide baseline data concerning sway in static sitting balance which may be useful in evaluating the postural instability in sitting of children with CNS dysfunction. Although the developmental trend observed in this study occurred in a linear fashion, it is hypothesized that, if a wider age range of subjects was studied, a maximum physiological stability threshold would be found. With regards to whether a change in seat surface inclination had an effect on stability in neurologically disabled subjects, the magnitude of change in radius was not clinically significant. Further work is needed to determine if monitoring sessions of longer durations would yield clinically and/or statistically significant results.

ACKNOWLEDGEMENTS

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BIOMECHANICAL SIMULATION OF A GENERALIZED PLANAR MANUAL MATERIAL HANDLING TASK: A NONLINEAR CONSTRAINED OPTIMIZATION MODEL

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INTRODUCTION

In pursuit of purposeful activities of life, human applies forces to the environment, which consequently loads its various joints. NIOSH (1981) stated over-exertion injuries associated with manual material handling accounted for 12 million lost work days. Three approaches have been suggested for prevention of low back pain: training, screening/selection, and workplace (job) design. The validity and utility of the recommended "safe" lifting technique (straight back/bent knee) has been questioned (Parnianpour et al 1987). Avoidance of the excessive loads on the joints is a rational objective that should be encouraged in the workers education and the workplace design. The following biomechanical model is to provide us with such tool. The purposes of this study are: a) to present the implementation of a static planar model of the generalized manual material handling task, b) to compare the optimum configuration at different locations of the hand and different magnitude of external forces, and c) to compare the predicted joint angles using different objective functions.

METHOD

A planar static model, composed of five bar-links, is developed to mathematically simulate a generalized material handling task. The inputs of the model are the anthropometric data of the subject, the horizontal (H) and the vertical (V) coordinates of the hands (position of the end effector), and the external force vector, F. Upon specifications of the hand location the system looses two degrees of freedom (DOF). The remaining three degrees of freedom make the set of the joint angles indeterminate. A nonlinear optimization method based on generalized reduced gradient algorithm (Lasdon et al 1978) is used to find the optimal joint angles which minimizes the cost (objective) function. Different cost functions are used: a) the sum of the square of the external moments of all the joints, which is called the global cost, and b) the square of the external moments about each joint, called the local cost. The minimization of the local cost is implemented to simulate the situation of the individuals with an injured joint undergoing a rehabilitation program, i.e. patients after back or knee surgery. The moments at the optimal joint angles and the values of the minimum cost functions are the outputs of the model. The equality constraints are geometrically derived in addition to the moments calculated about each joint (satisfying the equilibrium conditions). The inequality constraints are the physiological range of motion. The upper bounds on the torque generation capacity of each joint will be implemented in future studies.

RESULTS

The graphical display of the results of the optimization is shown in figure 1. The maximization and the minimization of the global cost show the best and the worst configurations. For this particular hand position (H=.3 m, V=.3 m), bending of the knee is recommended, but for slightly different location (H=.1 m, V=.3 m) a bent back is recommended. The optimum joint angles and the corresponding external moments at a given hand location (H=.3 m, V=.3 m) with different vertical forces (i.e loads with different weights) are compared in figures 2 and 3. The moments are highly affected by vertical forces but the joint angles are not. The location of the hand (H=.3m; V=.3, .8, 1.2 m) affects the global cost significantly (Fig 4). The effects of minimizing the local or global cost depend on the location of the load. The global cost is enormous when the external moments of the knee or the shoulder are being minimized.

CONCLUSION

This model may aid the workplace evaluation and redesign by identifying the infeasible "tasks" and the limiting factors, such as the excessive muscular torque and/or range of motion requirements at particular joints. The model may also be used in illustrating the proper lifting techniques. The results point to the importance of the proper work place design as oppose to proper lifting techniques.

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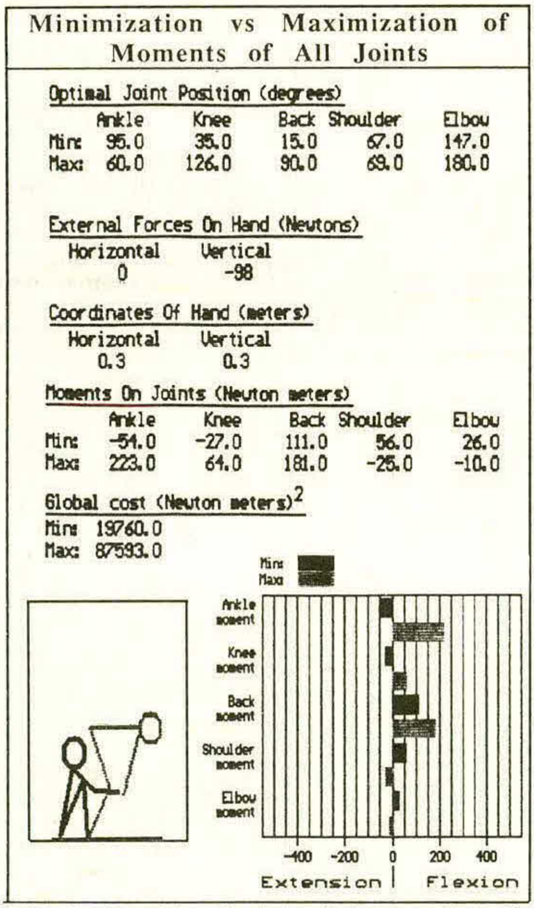

Fig. 1. Graphic display of the results of the optimization.

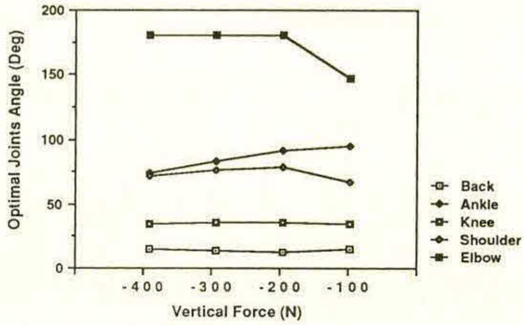

Fig. 2. The affect of the magnitude of the vertical force on the predicted optimum angular position of the Ankle, Knee, Back, Shoulder and Elbow joint (H=0.3m, V=0.3).

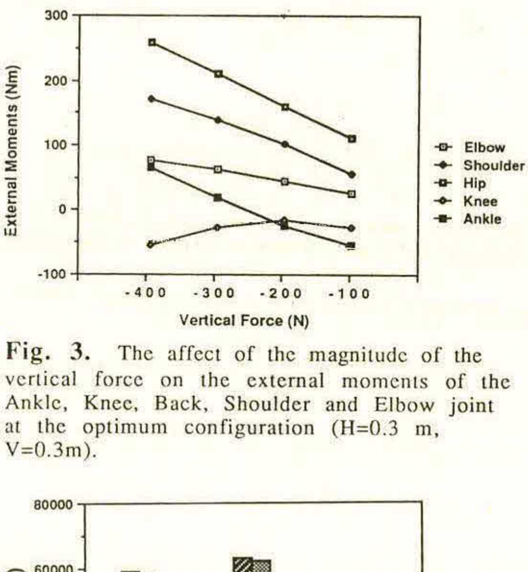

Fig. 3. The affect of the magnitude of the vertical force on the external moments of the Ankle, Knee, Back, Shoulder and Elbow joint at the optimum configuration (H=0.3 m, V=0.3m).

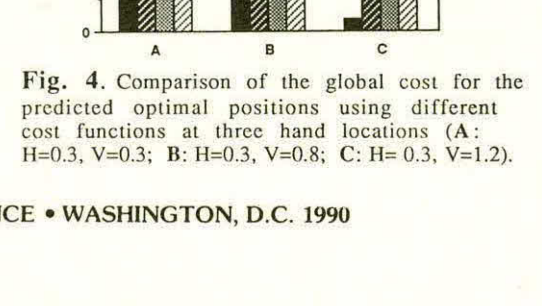

Fig. 4. Comparison of the global cost for the predicted optimal positions using different cost functions at three hand locations (**A**: H=0.3, V=0.3; **B**: H=0.3, V=0.8; **C**: H= 0.3, V=1.2).

A Myoelectrically Controlled Robotic Arm for the Biofeedback Training of Cerebral Palsied Persons

28.1

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Introduction

Several studies have provided strong evidence that the muscle activity patterns of cerebral palsied persons may be differentiated from those of able-bodied persons (e.g., Hallet and Alvarez, 1983; Rudin et al., 1987). Abnormally high EMG activity is one indicator of the presence of spasticity. This may be due to an inadequacy or abnormality in the intrinsic information provided via afferent pathways of the affected person. If so, then the performance of a motor task may be improved by providing augmentative extrinsic feedback which relates information concerning the intended and actual task performances. This principle was the basis for the current application of EMG biofeedback (Tse, 1989).

Methods

A system was developed using a robotic arm to provide a visual correlate to muscle activity. The strategy employed was to reward a subject under training for minimizing EMG activity in the upper arm while performing an elbow extension movement. Continuous monitoring of the biceps and triceps EMG activity was used to control the activity of a small robotic arm which provided the participating subjects with external (visual) feedback to augment their own internal feedback from muscle activity. The Microbot Minimover-5 (MM5), a six jointed, table-top robotic arm system was used in this study. The MM5 was controlled from an 8-bit parallel port, and it was moved in a pre-programmed fashion. The speed at which the MM5 moved was inversely dependent upon the overall level of activity in the biceps and triceps.

Bipolar active (i.e., "dry") electrodes were developed for the acquisition of surface EMGs. A quad operational amplifier IC was included within the electrode housing. Amplified, low-pass filtered surface EMGs were obtained from the biceps and triceps muscles to provide control signals. The filtered EMG signals were digitized and input to the IBM-PC/XT. A controller program examined the results of a mathematical combination of the two signals and instructed the MM5 to respond appropriately. Software included control of the MM5, pre-session testing routines, data collection, and EMG signal processing. The source code for these functions was written in either FORTH-83 or 8088 assembly language.

The data analysis for the two single-subject studies was designed to test for statistically significant differences among or between EMG recordings obtained under the various trial treatments and identification of specific trends in EMG parameters (biceps, triceps and ratio of the two). One way analyses of variance (ANOVA) were used to determine whether EMG data of one treatment (e.g., no feedback trials with the MM5 off) exhibited differences that could be considered statistically significant when compared to the EMG of other treatments. A trend analysis was performed to reveal any significant linear components in the progression of EMG activity levels over a series of related trials. It was assumed that any differences found among the trials were the result of carry-over effects from preceding trials. Each study followed a single-subject (N=1) A-BBA-BBA-BB-A experimental design where the treatment (B) phase used robotic arm feedback and the baseline (A) phase did not.

Subjects

Studies were conducted with two cerebral palsied persons. K.L., a 23 year old female with CP, displays some degree of spasticity and is a wheelchair user. Though her use of either upper extremity is limited, functional ability of her right arm is clearly superior to that of her left. P.S., is a 53 year old female with CP. She displays some spasticity, uses a wheelchair, and depends on her right upper extremity for functional tasks.

Results

There was statistically significant evidence that the biofeedback training protocol did effect changes in EMG activity levels of both subjects. Though the results of the two single-subject studies differed in some aspects, there were in fact, some qualitative similarities. The most obvious similarity between the two studies was that within-sessions, feedback training had little effect, but across-sessions, there were some significant changes in EMG activity levels. For K.L., the triceps EMG activity decreased markedly across-sessions while, for the most part, the across-sessions differences in biceps EMG levels were not significant. The opposite result held true for subject P.S., who exhibited stable triceps activity and a progressive decrease in biceps activity across-sessions. One possible explanation for this difference in effects is that the two subjects' motor strategies may have been different. Whereas K.L.'s initial motor pattern may have included an overflow of triceps activity, the motor pattern for P.S. may have included excessive biceps activity. Each subject exhibited spasticity in both the biceps and triceps muscles. Another factor is that training of a motor skill may be more an adjustment process involving the ratio of opposing muscles' activity levels rather than that of the individual muscles (Sakitt et al., 1983). This effect was indicated by the fact that, for both CP participants, biofeedback significantly affected only one of the two muscles. The generally consistent, within-sessions and across-sessions changes in the ratio data of both subjects might then be considered as supporting evidence for the presence of a biofeedback effect.

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THE DEVELOPMENT OF A ROBOT WORKSTATION FOR THE DISABLED.

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ABSTRACT

The design and development of a robotic workstation for the disabled is described. The manipulator is of a SCARA geometry, and integrated with the workstation. The user interface, by which the user can control the arm either directly or using preprogrammed routines, is a scanning menu system on a small microcomputer.

INTRODUCTION

The use of robotic technology offers great potential to improve the independence of disabled people by performing a wide range of tasks. There are various ways of applying robotics, at varying costs and requiring varying degrees of structure of the environment. The approach being followed at the Institute is to use a relatively low cost robotic arm in a semi-structured workstation environment.

BACKGROUND

The initial work at the Institute used a commercially available arm, built into a desktop workstation [1]. Experience in the development of this system and trials with disabled people have given valuable information for use in the development of the current system.

DESCRIPTION

Workstation

The earlier tests have shown that the overall size of the workstation is very important, especially when used in a domestic environment. The new system has therefore been designed for efficient use of space, with the manipulator integrated into the workstation. The size of the workstation is that of a standard desk (4'6" x 2'6"). Storage is organised into a single shelving unit. This is arranged at the back of the desk, allowing good visibility, unobstructed by the structure of the arm. Figure 1 illustrates the workstation with the arm in a parked position. The workstation is arranged for computer use, retrieval of books and operation of an automobile cassette player, plus a coffee maker.

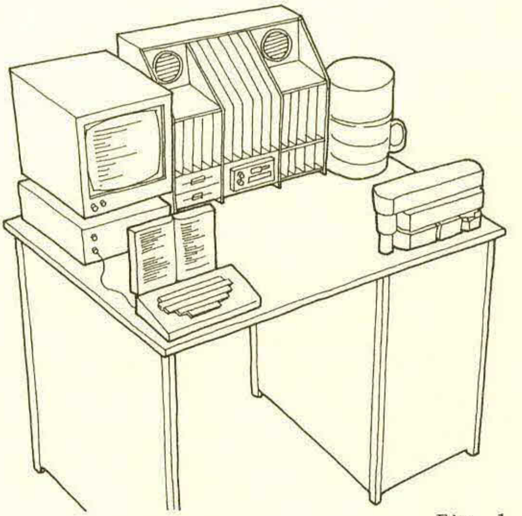

Fig. 1

Mechanical Design

The manipulator (Figure 2) is of a modified 'SCARA' geometry. An articulated arm is positioned in the horizontal plane by light rotary actuators at shoulder and elbow. The whole arm is lifted by a vertical actuator at the origin. Yaw and roll freedoms are provided at the wrist.

All joints are driven by geared d.c. servomotors, via additional gears and/or timing belts. Positional feedback is provided by incremental optical encoders.

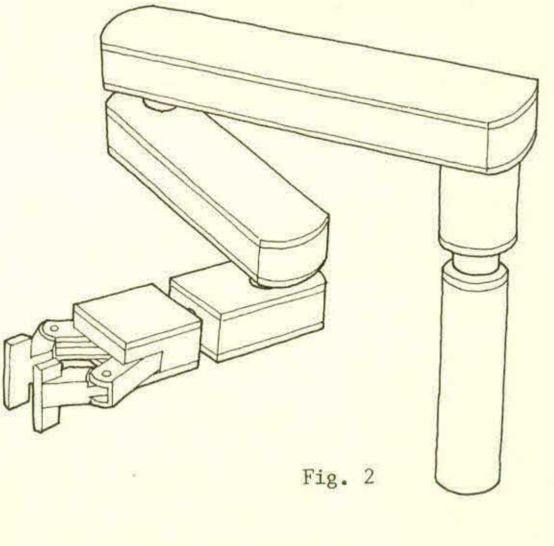

Fig. 2

The vertical actuator is housed in a cabinet below the desktop. It incorporates a constant tension spring to counterbalance the arm. Motion is transmitted by a polished stainless steel tube sliding in a pair of low friction plastic bushes.

The rotary actuators at shoulder, elbow and wrist do no work against gravity. Thus the motors are small enough to be mounted in the arm, and the drive train is simplified. Manufacturing costs are minimised by using the same design for each actuator.

The hollow arms are light and strong, all mechanisms and cables being hidden inside. Construction is from standard aluminium extrusions and so the cost of special mouldings is avoided at this stage.

Electronics Hardware
The electronics cabinet of the workstation houses the power supplies and 19" Eurocard rack for the robot and workstation appliance control. The rack contains a Control Universal EuroBEEB II 65C02 based microcomputer accessing six separate motor drive cards. Each of these cards is a speed controller for one degree of freedom. Position control is achieved by the EuroBEEB monitoring the incremental encoder interfaces and issuing speed control instructions accordingly. Other cards mounted in the rack interface the EuroBEEB with sensors on the manipulator and allow the user to control mains powered appliances.

The construction of the electronics is designed to the IEC electromedical equipment safety standard IEC 601.

Software.
The software is in two main parts, the robot control software and the user interface. The robot control software is written in 6502 assembler, as provided on the EuroBEEB board, and is stored on EPROM. This includes the basic control of the robot, both under direct user control and preprogrammed routines, the control of peripheral devices and the storage and manipulation of routines. For straight line movement the robot control includes a look-up table to convert between XY position in a horizontal plane, and joint positions of the arm. The preprogrammed routines are stored in battery backed RAM on the EuroBEEB board.

User Interface.
It is intended that the user interface should be easily adapted according to the physical ability of the user, and hardware availability. The initial user input is by two switches, either directly connected or via a two channel infra red link. A menu scanning system on a separate microcomputer (currently a BBC Micro) is used to select options. This computer sends and receives data from the EuroBEEB computer along an RS423 serial link. The user control software is loaded on power-up, though the microcomputer is also available for user applications such as wordprocessing. The user is able to either control the arm directly or to call up a preprogrammed routine. An important facility is for the user to be able to interact with the system during the replay of a routine. Therefore, if an object is not aligned correctly, the user can interrupt the routine, adjust the position as required, and then return to the preprogrammed routine. The input system was developed in trials with disabled users in the earlier phase of the project.

At a later date it is hoped to incorporate the user interface as a pull-down menu on the user's computer. Another option intended is to incorporate a simple user interface on the EuroBEEB system which can be used without the need for a separate microcomputer.

CONCLUSIONS

Good progress has been made in the development of the current system, and the new manipulator has been constructed. It is hoped to carry out user trials in the near future, with contacts developed in the earlier phase of the project.

ACKNOWLEDGEMENTS

The financial support of the Wolfson Foundation is gratefully acknowledged.

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Task-Oriented Control of a Robot Manipulator Part II: Implementation on the RTX

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ABSTRACT

The principles of Task-Oriented Control of a robot manipulator are described in [5]. To test these principles, the *sweep mode* was implemented on the RTX manipulator. A virtual four bar linkage model simplifies the development of the robot position and velocity solutions.

TASK-ORIENTED CONTROL

Task-oriented control is a method of interactive robot control which links the geometries of the manipulator and the task being accomplished. The result is a control algorithm which more closely resembles the obvious task characteristics.

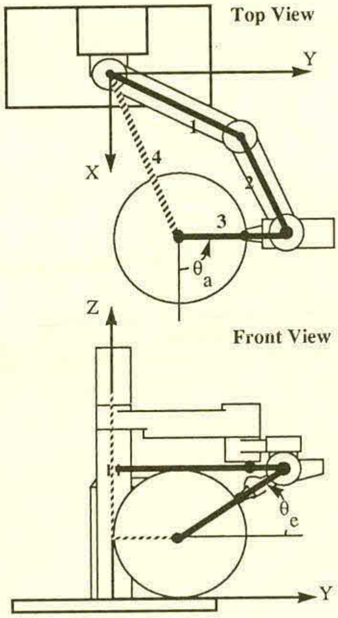

Figure 1: Four Bar Linkage Model of the RTX

To model the motion of the robot, a three dimensional virtual four bar linkage is superimposed over the geometry of the manipulator and linked to the task geometry. Figure 1 shows the top view and front view of the RTX with the four links marked as well as the reference azimuth and elevation angles, θ_a and θ_e. In three dimensions, the task geometry is modelled as a sphere.

The four bar linkage model offers several advantages to interactive control of a robot. As a closed chain, the number of degrees of freedom of a planar four bar linkage is reduced to one. In three dimensions, the number of degrees of freedom of the task, modelled as a sphere, may be separated so that only two degrees of freedom need be controlled at any time.

VALIDATION TESTS

To validate the four bar linkage model approach, the sweep mode of task-oriented control was implemented on the RTX. Sweep mode is trajectory planning of an arc in three dimensions which uses the velocity and position solutions of the four bar linkage model to determine the motor parameters required at the beginning of each control interval to provide the desired motion.

The hand of the robot was positioned on the task sphere for various target center locations and was made to follow an arc along the sphere while maintaining the orientation of the hand towards the sphere center. The azimuth and elevation angles were varied independently for a series of arcs of approximately 28° for several sphere target center locations.

COMPUTER SIMULATION

To validate the velocity solution independent of possible errors introduced by the robot, the approach was first implemented in a computer simulation. In this way, only those errors inherent to the control algorithm would be apparent and a base line comparison for the robot would be generated. The simulation was modified to include errors inherent in the robot implementation to more closely model the RTX performance.

THE RTX

The UMI RTX, distributed by PRAB Command, is a six degrees-of-freedom manipulator used extensively in rehabilitation robotics research and applications. The RTX used in this work is controlled through an RS232 cable at 9600 baud by an Intel 80386 based IBM compatible PC running at 20 MHz with an 80387 math coprocessor. Motor parameters are updated every 16 milliseconds and optical encoders provide the position of each motor while the manipulator is running[1].

The control software is in Microsoft C and low level functions of the ASEL RTX Control Library[2] are used as the robot drivers.

RTX IMPLEMENTATION

Path planning using the position mode of the RTX required the motors to come to a stop before moving through the next interval. The resulting motion was unacceptable. Therefore, it was necessary to implement a velocity control algorithm to obtain smooth motion. Only open loop control was considered for this initial implementation. The sampling interval used in the test runs was 150 milliseconds based on the time requirements of the sampling interval steps. The steps of the control loop algorithm and their times are listed in Table 1.

STEP	DESCRIPTION	TIME(ms)
Position Solution	Four bar linkage position solution	1
Velocity Solution	Four bar linkage velocity solution	1
RTX Mapping	Code to meet RTX protocols	1
RTX Communication	Writing SPEEDS and directions to RTX	70
Error Analysis	Reading positions from RTX	65
	TOTAL	138

Table 1: Control Loop Steps and Times

ERROR ANALYSIS

The path error is manifested in three error values: 1) the magnitude of the error off the path, 2) the angle error off the driving angle, and 3) the orientation angle error. The comparative accuracy of each path was found by examining the average value of the magnitude of error of the actual location of the virtual sphere target center off the theoretical target center as the hand traversed the arc. This value is denoted by $\overline{E}_{tc}$ and is the cumulative effect of the three errors listed above . $\overline{E}_{tc}$ is used as the measure of path accuracy.

constant	Azimuth		Elevation	
	AVG	FIN	AVG	FIN
Computer Simulation	3.667	6.969	2.430	3.920
RTX Implementation	3.684	3.784	4.179	4.771

Table 2: RTX Target Center Errors, $\overline{E}_{tc}$ (mm)

RESULTS

Table 2 lists the average error and final error values separately for arc paths of constant azimuth and elevation angles. The constant azimuth data includes 28 paths. The constant elevation data includes 24 paths.

A typical path followed by the robot hand for varying azimuth angle is shown in Figure 2. The dotted line is the theoretical arc and the solid lines are the actual target center and hand path. The radius is 90mm.

CONCLUSIONS

Open loop control of the RTX resulted in errors that were less than 5 millimeters over 28° arcs. The four bar linkage model results in a velocity and position

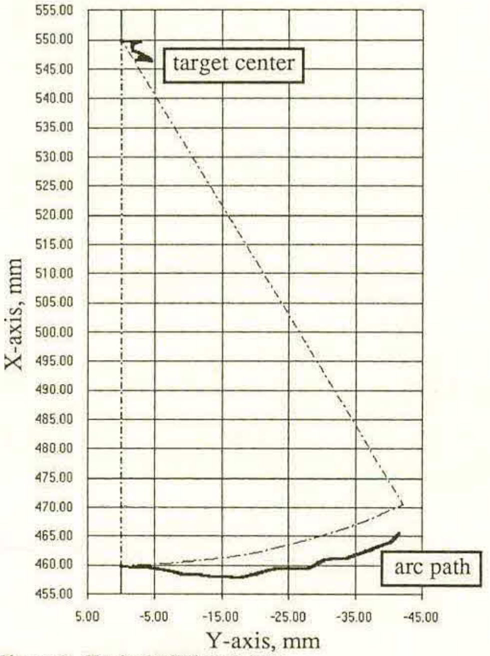

Figure 2: Typical RTX Path Plot

solution such that the calculation times are minimal as compared to the communication time requirements (see Table 1). Since the four bar linkage velocity solution is a geometric one, the solution is quicker than comparable matrix solutions.

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Funding for this research was provided by the Nemours Foundation.

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FAIL-SAFE FEATURES OF A MOBILE ROBOTIC PLATFORM

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INTRODUCTION

The robot has a promising future in health care. Bringing this technology into the main stream will involve two steps. The first is to design, build and test the robot in the laboratory. This step is in progress in research programs across the country.

The second step is to move the robot from the research lab to the real world. This move will present a number of challenges, the most important of which is safety. A 1985 survey on the future of robots in health care concluded, *safety is and continues to be the number one issue that transcends all other questions* (1).

A research project is in progress which will build a semi-autonomous mobile robotic platform to be used for rehabilitation applications such as transporting a robot arm between workstations or accompanying a person moving from room to room (2). In order to function in an unstructured environment, the robot is equipped with ultrasonic and infra-red sensors which allow it to visualize its surroundings and avoid collisions with stationary or moving objects. The long term goal of the project is a self-guided mobile robot which can function safely and reliably around people.

With design and construction under way, planning for testing and implementation has begun. A primary focus of this planning is a careful assessment of current hardware and software with the aim of including comprehensive and redundant safety features in the system. This paper outlines these features.

BACKGROUND

The platform being developed is based on a commercially available robot and features a ring of 24 ultrasonic transceivers for detecting obstacles and an infra-red beacon system for determining absolute position.

A unique feature of the system is the navigation and obstacle avoidance software that will be used to control the platform. This software was developed in a separate research project (3). It has been ported to the mobile platform ('rehab robot') described here and is undergoing further development aimed at rehabilitation applications.

MATERIALS

The rehab robot is a three-wheeled platform which has four component subsystems, presented as a block diagram in Figure 1.

Onboard *Master Control* Computer This is an IBM PC-compatible 80386-based computer that exercises control over all other subsystems. The path planning and obstacle avoidance software runs in this computer.

Motion Control Subsystem This subsystem consists of the motor control computer, the steering motor and the drive motor. It receives digital motion commands from the *master computer* and translates these commands into robot movement by driving the two motors.

Ultrasonic Ranging Subsystem This is the chief obstacle detection system. It is composed of a ring of 24 ultrasonic sensors controlled by a dedicated computer. Several times each second this computer calculates the distance from each one of the sensors of the sonar ring to the closest obstruction in the direction that that sensor is aimed.

Infra-red Beacon Detector This is an infra-red (IR) sensitive camera mounted to swivel 360° allowing it to be pointed in any direction. It is controlled by a separate computer. The system is used to optically locate small IR beacons placed in known positions throughout the robot's environment. Each beacon is a matchbox-sized IR transmitter which is visible to the robot's detector.

In normal operation the *master computer* controls all aspects of robot operation. It is continually asking for and receiving sensor information about the surrounding environment from the sonar and infra-red computers. From this data it can plan an appropriate path for robot travel. This path information is then reduced to elementary steering and drive motion commands which can be sent to the motor control computer for actual execution.

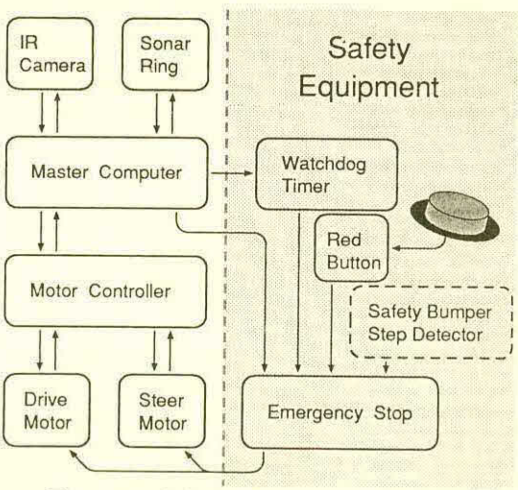

Figure 1. Block Diagram of Mobile Platform

METHODS

The safest global response of a mobile robot to an emergency situation is to stop. The basic mechanism to accomplish this function, the *emergency stop switch* (*E-stop switch*), is included as part of the commercial version of the robot (see Figure 1). When it is triggered, it immediately cuts all power to the drive and steering motors. This *E-stop switch* overrides all other components in the system, including the *master computer*.

In the standard robot, the *E-stop switch* is triggered by a large red button on the side of the robot; the button must be activated by a human observer. To make the rehab robot as safe as possible, several additional *E-stop* trigger sources are being added to the modified platform. The complete list of *E-stop* triggers includes:

The Big Red Button, mentioned above.

The *Master Computer* This can trigger an *E-stop* any time it detects an unexpected condition in itself or any of the modules it controls.

The *Safety Bumper* Similar to the bumper on a car, it encircles the platform and detects any physical contact with objects around the robot.

The *Watchdog Timer* This new circuit is discussed below.

The robot breaks down into *electromechanical devices* (*EDs*) and computers/software. The *EDs* are not a major safety problem for three reasons. They are all commercial products which have been thoroughly tested and documented. Most are simple devices with a limited number of failure modes. Finally, all the *ED* systems are monitored continuously by one of the four computers.

These computers provide the intelligence of the platform but also contribute most of the safety concerns. The software running each of the computers is unique for this application. Despite careful testing the programs are complex enough that there is always the chance of a software 'bug' disrupting system operation.

The platform is designed to fail safely (i.e., to stop) when any of the computers stop working due to either a hardware breakdown or a software error. The main instrument of this safety system is the *master computer*. The control program in this computer sends a command query to each of the other computers 30 times each second. If any computer fails to respond with a coherent, *All-Systems-Go* reply, the *master computer* will activate the *E-stop switch* immediately. This procedure protects against failures both in the three peripheral computers and in the hardware that those computers control.

The remaining problem is a potential failure in the *master computer*. A simple circuit, called a *watchdog timer*, has been added to the platform to monitor this computer. The *watchdog timer* is designed to start at one-quarter second and count down to 0. When is reaches 0 ('times out') it activates the *E-stop switch* (see Figure 1). Each time the Master Computer sends a signal to the *watchdog timer* it is reset to one-quarter second. The reset signal from the *master computer* is normally sent 30 times each second as part of the main computer control loop. If the *master computer* stops sending this repeated signal for too long the timer times out and activates the *E-stop switch*.

DISCUSSION

During early testing of the robot it was not uncommon for the navigation program running in the *master computer* to malfunction or 'crash'. When this occurred it stopped sending regular control commands to the motor control computer. If the robot was in motion when the *master computer* crashed, the robot continued to move with a constant course and speed, colliding with anything in its path. The presence of the *watchdog timer* prevents this type of very dangerous situation.

FUTURE WORK

The measures discussed above address various dangers posed by internal robot failures. Future work will address safety concerns introduced by factors external to the robot. This will include a *safety bumper* mentioned above and a *step detector* to warn the robot when it approaches the top of a staircase or other sudden drop-off.

ACKNOWLEDGEMENTS

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VOCATIONAL ASSESSMENT AND PLACEMENT: AN APPLICATION FOR AN INTERACTIVE ROBOT WORKSTATION

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INTRODUCTION

Vocational rehabilitation refers to the process of providing renumerated employment for people who, because of a physical or mental disability, are unable to share in the mainstream vocational opportunities. This paper is concerned with the vocational rehabilitation of physically disabled people who have no, or perhaps very poor, manipulative function or reaching ability. While physical disability does not justify the exclusion of the disabled population from gainful employment, in reality the vocational opportunities for the physically disabled are severely restricted. The limited opportunity for disabled people to participate in vocational activities is among the most damaging consequences of physical disability.

The Papworth Group operates a number of small-scale light industries which are concerned with the manufacture of a variety of products including electronic assemblies, electric wheelchairs, leather goods, and stationary. Furthermore, it is the policy of The Group to serve as an employment base for physically disabled people. The high quality of the products from The Papworth Group enables it to compete for a share in the consumer market with products from mainstream commercial industries. It is necessary, therefore, for productivity levels, in addition to quality, to be kept relatively high. Since most of the workshops are engaged in short, low-volume production which is not suited to the application of hard-automation, the work remains labour intensive.

A recent venture of The Papworth Group was the establishment of an Assessment and Development Centre which is concerned with the prevocational assessment of prospective employees and subsequent on-the-job assessment of a workers performance within a job activity. Within the context of the assessment are issues including the revision of manufacturing methods and practice with a view to exploiting high technology in order to enhance the employment opportunities for the physically disabled. One such high technology component is an interactive robot workstation which has been developed and applied within an educational setting to enable physically disabled pupils to carry out prevocational activities such as chemistry experiments.[1,2]

ASSESSMENT AND PLACEMENT

The assessment procedure focuses on evaluating an individual's aptitudes, skills and abilities, so that the optimum employment placement can be provided. Psychometric testing using scientifically validated instruments enable an individual to discover his/her own particular vocational abilities. Work samples are utilised to provide an evaluation of the individuals abilities on a particular task, and to provide the individual with a realistic vocational situation in which they can undertake a preliminary trial in a chosen field of work.

Within the assessment, emphasis is placed on evaluating the individual's ability to operate within a typical workstation. Reach, grip, manipulation, and finger and manual dexterity influence the ability of a person to interact with his/her working environment. If limitations in these areas can be overcome, an individual previously viewed as unproductive may be enabled to work within a chosen field, providing them with increased job satisfaction.

The Papworth Group offers a wide variety of occupations, though clearly not all primary interests can be catered for. When a suitable placement has been located, adaptations to the actual job or work situation may be necessary to enable the individual to work to their optimum production rate. These adaptations, which take a variety of forms, may affect only a small range of the activities involved, or can radically alter the entire approach to the work activity.

The extent to which a work situation can be adapted is dependent not only on the individuals ability, but also on the technological development of assistive devices including robot systems. It is possible that entire manufacturing methods and practices could be reviewed to take full advantage of high technology in order to give physically disabled individuals access to the work setting. Further developments may also enhance the prospects of those currently employed, to further develop their skills and abilities, enabling them to achieve career advancement.

INTERACTIVE ROBOTICS

In production environments, the robot has the potential to increase productivity by establishing a high rate of assembling or packaging. While an industrial robot approach does not contribute to a solution to the problems encountered in vocational rehabilitation, it is proposed that appropriate robot technology has the potential for increasing the range of activities which may be carried out by disabled employees within a work environment. There is potential for increasing the productivity of the individual disabled workers through the use of robot technology, and opening existing production activities to people having severe physical disabilities.

An interactive robot system is proposed as a tool for use by the disabled person to aid in the execution of a particular part of a manual activity. The robot, under the high-level control of a disabled worker, has the potential to replace or augment the worker's restricted manipulative function while leaving the worker in ultimate control of the activity. It is proposed that such a system could be used by a wheelchair-bound employee to extend his/her reach, thereby increasing the effective volume of the workspace. For example, in an assembly activity, boxes of components and finished assemblies could be moved in and out of the immediate workspace by the employee giving high-level commands to an intelligent robot. In addition, the robot could be used to position objects within an assembly activity.

OPERATIONAL MODEL

The operational model for a vocational application, which is illustrated in Figure 1, comprises *pathways* which define the interactions between the disabled employee (user), the supervisor, and the robot. Pathway 1 corresponds to the normal exchange of information between the user and the production supervisor. The mode of communication may be voice, sign language, head gestures, eye spelling, or a wide range of augmentative communication devices. The supervisor provides the user with information regarding the vocational activity and use of the robot or associated equipment, and feedback regarding the user's vocational performance. The user communicates comments and requests to the supervisor regarding the requirements of a particular activity.

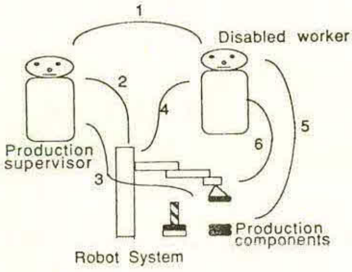

Figure 1 - Operational Model

Pathway 2 provides the supervisor with a method of interacting with the robot system, using a keyboard or keyboard emulator, for the purpose of programming new robot tasks or modifying existing ones. Pathway 3 lets the supervisor introduce or remove objects from the user's workspace. In an assembly process, the supervisor could introduce assembly components into the workspace and remove the assembled products. Pathway 4 facilitates communication between the user and the robot system using suitable input devices including keyboards, keyboard emulation devices such as a voice recogniser, switches, and augmentative communication devices. This channel enables the user to activate preprogrammed robot tasks, to instruct the robot at a high level, and to control the robot in a manipulator-like fashion. It is also possible that the user could create or modify robot applications to take better advantage of the features of the robot system.

Pathway 5 provides visual feedback to the user regarding the robot-assisted activity. While direct visual feedback has been chosen for the demonstration activity, it is expected that indirect visual feedback, for example through the use of video monitors, may be useful in certain applications. Depending on the physical ability of the user, he/she may physically interact with the robot, along pathway 6, during an activity.

DEMONSTRATION ACTIVITY

A demonstration activity, which involves the assembly of a number of colour-coded nut and bolt assemblies and the sorting of the finished assemblies into colour-coded bins, has been devised to illustrate the potential for a vocational application. In addition to requiring both fine and gross physical manipulation ability, the activity required a component of human decision-making which could not be easily replaced with machine intelligence. The activity was preprogrammed in CURL to control, via a Votan voice recogniser, a robot workstation based on the UMI RTX robot.

Before starting the assembly operation, the robot is instructed using high-level CURL commands to arrange the workspace such that the components required for manipulation by the worker are within his reach. Bins of components are initially placed by the supervisor so that they can be viewed by a camera which is part of the workstation. Alternatively, the bins of components could be retrieved from a shelf or storage area within reach of the robot. Once the workspace is arranged, the preprogrammed robot actions can be selected, again using voice commands, to manipulate the assemblies during the various stages of the production. The user supplements the preprogrammed motions with high-level commands and manipulator-like control of the robot as required to complete the activity.

From this demonstration activity a number of important ideas emerge. First, further investigation of a role for moderately priced interactive robot systems in semi-automated production environments is warranted. It appears to be feasible for a disabled person to use his/her decision-making ability and residual manipulative function, augmented with the manipulative power of a interactive robot system, in order to participate in productive employment. Second, a robotic workstation application to vocational rehabilitation could prove to be a valid and affordable approach in assisting the physically disabled. Current robot technology is better suited to repetitive pick-and-place activities that are common in small-scale production than to the delicate manipulation requirements for assisting in daily living tasks such as feeding and hygiene. With an application in a light manufacturing industry, it may be possible to exploit the suitability of commercial robot technology to production tasks and to give the disabled employee a critical, decision-making role in the production process. In an application such as this, the focus of the research shifts away from the design of appropriate robots, towards issues such as interactive control, application programming, safety, and error detection and recovery.

ACKNOWLEDGEMENTS

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Development of a Software Library for the Data Glove

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ABSTRACT

This paper outlines the development of a library of functions designed to provide the user with access to the Data Glove, a hardware system providing data representing finger angles, hand position, and orientation. The library, written in the "C" programming language, has functions which setup communications, calibrate both the angle and position measuring system, and read angles and positions from the data glove. The use of each of the functions is outlined briefly.

INTRODUCTION

VPL Research has combined their Data Glove with the 3SPACE Isotrak by Polhemus Navigational Science into a single packaged system which provides a flexible man-machine interface. In order for this device to be used easily and effectively in a C programming environment, a set of functions has been developed which allow an applications programmer to access the data reported by the Data Glove in a simple manner.

Currently the Data Glove Library consists of 22 functions which allow the establishment of communication with, the calibration of, and various means of reading finger angles, hand position, and orientation from, the Data Glove. While the major motivation for the design of the Data Glove functions was to interface the device with a rehabilitation robotics system, the functions are general enough to be used in any application where data from the glove is to be utilized.

In addition to the functions themselves, six application programs have been written for inclusion in the software package. These programs use the Data Glove Library functions to aid the user in setting up calibration tables for both finger angle measurements and 3SPACE position measurements as well as demonstrate the various abilities of the glove.

DATA GLOVE HARDWARE

The Data Glove System consists of two separate sensing devices combined into one unit. The finger angle measurement system consists of a spandex glove equipped with a set of fibre optics. When the fibres are bent, corresponding to the bending of a finger joint, light is lost from the optic fiber in proportion to the angle of bend. Thus the Data Glove system measures this loss of light and transmits data about the degree of bend at each of ten finger joints[1]. The 3SPACE position sensing system uses magnetic sending and receiving units to measure distances in the x, y, and z directions as well as orientation angles of role, pitch, and yaw. The data from these sensors may be sent back to the host computer either separately or in combination.

<u>3-Space Calibration</u>

Because of the magnetic nature of the position sensing device, the 3SPACE Isotrak is greatly susceptible to interference from metals which may be located in the environment. A function has been designed which reads raw data from this device and constructs a set of straight line approximations to the actual position values. Using the functions provided, a set of calibration curves have been constructed in our labs. Use of these curves allows the measurement of position over an entire hemisphere with a radius of 28" with an average accuracy to within 0.15 inches, and a worst case error of 0.30 inches near the maximum range. The curves used for position calibration are contained in a data structure and is called by a correcting function whenever needed.

<u>Joint Angle Calibration</u>

The loss of light around a bend in the optic fibre is logarithmically proportional to the angle of bend. In order to convert this to a linear function, finger angles must also be calibrated. The calibration of finger angles is much simpler than that of the Isotrak, since only two points need be recorded. Data is taken with the finger flexed and extended, using this data, a curve giving angles over the entire range of finger motion can be constructed.

SOFTWARE DESIGN

The Data Glove software library was designed to meet two objectives:

1. Provide the user with a set of functions which return position and finger angle data in a meaningful form.
2. Isolate the user from the communications and decoding processes involved.

In attempting to accomplish these objectives the library functions have been divided into three distinct groups:

1. Those functions which deal with the entire Data Glove, such as functions that open and close communications
2. Those functions which pertain to the finger angle data.
3. Those which pertain to the position data.

<u>Data Glove Functions</u>

Functions dealing with the entire Data Glove system can be divided into three groups:

<u>Host-Glove Interfacing</u>: There are three functions which

1. The design of the glove presumes that movement of the distal and proximal inter-phalangeal joints occur in tandem. The glove only measures the angles of the proximal interphalangeal and metacarpal-phalangeal joints.

initialize, reset and terminate communication between the Host computer and the Data Glove System.

Communication: There are two ways of communicating with the glove. The simplest of these is to send out a single command and receive one record of data. Alternatively, the Data Glove may be read at 30 or 60 Hz. In this case, a continuous stream of data records are sent by the Data Glove to the Host. Three functions control this second, more complex, means of communication. These three function:

1. Send out a command to turn on or turn off the data stream.
2. Read one or more records from the data stream.
3. Interpret the data.

Error Handling: While every function in the library returns a flag of type boolean (value 1 or 0) to indicate an error event in that function, each function also calls an error function when an error occurs within that function. This error function is modeled after the math error function in the Microsoft C compiler[3]. The Data Glove Library is supplied with an error function which reports each error on the screen at the time it occurs and offers the user the option of exiting the program or continuing. Alternatively, the user is encouraged to write his/her own error function using the codes passed from each library function.

Finger Angle Functions

Data Glove functions which deal with the finger angle data can also be divided in three groups:

Calibration: These functions record, build, and download to the Data Glove system a set of curves (known as a calibration table) which interpret the raw logarithmic data coming from the glove as an angle between 0 and the maximum degree of bend.

Data retrieval: One function reads data from the Data Glove and passes it back to the calling program in an array of ten characters. Each character represents a single finger angle.

Calibration Table Storage: Once a calibration table has been constructed it can be saved or loaded from a disk file; two functions are provided for doing this.

Three Space Position Functions

The 3SPACE position functions are divided into three sets, analogous to those provided finger angles: 1) Calibration, 2) Data Retrieval, and 3) Calibration table storage. The major difference between the two systems is in the complexity of the calibration and the manner in which each table is stored. In the case of the 3SPACE calibration table, it resides in the Host computer in a dynamically allocated array. The finger angle calibration table, on the other hand, must be downloaded to the Data Glove System before it can be used.

The Demonstration Programs

In addition to the Data Glove Library the software package contains five demonstration programs:

1) Position Calibration [*posicali.exe*]: This program guides the user through the layout and recording of a number of points which are then used to build a position calibration table. The user may choose whatever number of points he/she wishes.

2) Finger Calibration [*fngrcali.exe*]: The program allows the individual calibration of all 10 finger joint angles. It guides the user through this process using a graphic of the hand and written text.

3) Demonstration of Finger Angles [*demofngr*.exe]: Using a graphic of a hand, this program demonstrates the reading of angles from the Data Glove.

4) Demonstration of Position [*demoposi*.exe]: This program draws a cross on the graphics screen. The position of this cross moves in real time in proportion to the movement of the position sensor. At present only 4 of the six dimensions are represented in this demonstration. These are: x, y, z (z controlling the size of the cross) and roll (roll controlling the angle the cross makes with the horizontal and vertical axes). The author plans to change this program so it will give a graphical representation of the 6 dimensions of the position sensor.

5)Glove to Disk Recording [*glov-dsk*.exe] This program allows the user to record finger angles and position data from the Glove at up to 60 hz. and record the data in a disk file.

FUTURE WORK

Future work with the Data Glove Library will be in two distinct directions. First the glove will be interfaced with the programming environment project and the usefulness of the glove as an input device to the RTX will be tested[4]. In a second area of investigation the data glove will be used as an assessment tool for upper extremity functional evaluation..

ACKNOWLEDGEMENT

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A SURVEY OF POTENTIAL USERS OF AN ELECTRIC WHEELCHAIR MOUNTED ROBOTIC ARM

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ABSTRACT

This paper presents the results of a robotic aid survey which was conducted to determine the needs and abilities of electric wheelchair users. The results of the survey will be used to develop a low-cost electric wheelchair mounted robotic arm for use by the physically disabled to facilitate rehabilitation. One of the major findings was that 79% of the survey subjects had no employment of any kind. Of all the areas of rehabilitation technology, employment of the severely disabled with the aid of robotics is one of the most promising and socially relevant.

INTRODUCTION

Many robotic systems have been designed and developed for the physically disabled over the last twenty years. Most of these systems have failed to reach the production stage due to the lack of basic research at the initial stages of the project and the high cost of this new technology. The result of not conducting initial research or conducting the wrong type of research is that the final design will not meet the needs and requirements of the end user.[1] The high cost means that those who would most benefit from the equipment cannot afford to buy it.[2] The first stage of any product design should entail research into the potential user population. In the case of a robotic aid for the physically disabled certain information is required:

1. General information on age, sex, accommodation, employment and pastimes.
2. Detailed information on the types and levels of disability.
3. Detailed information on daily living tasks.
4. Information on input device familiarity.

The above information could be obtained either through personal interviews, a detailed questionnaire or a mixture of both.[3]
By selecting and weighting the design criteria an optimum design of system can be achieved. This procedure will help to reduce costs to a minimum and hence will make the final system as accessible to the disabled population as is practically possible.

SURVEY METHOD

The survey was undertaken by the author together with staff and students from three occupational therapist training colleges within the U.K. over a one year period ending in June 1989. Survey subjects were contacted through hospitals, charitable homes, spinal units, special schools and the Disablement Services Association (the government organisation which issues electric wheelchairs to the disabled community). The survey was conducted using a four-page questionnaire containing over 110 questions. The majority of the survey subjects were interviewed personally, though some were posted the questionnaire. At the end of the survey a total of fifty questionnaires had been successfully completed.

RESULTS

The main results of the survey were that the average electric wheelchair user will be 40 years old, single (68%), living at home (58%) with family (40%) and with no employment of any kind (79%).

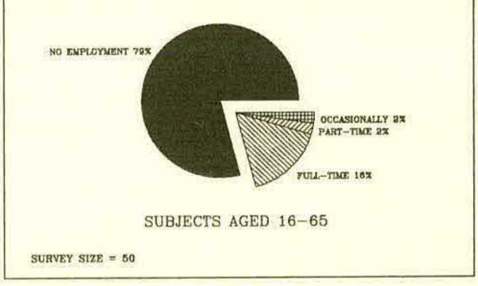

Figure 1.

The most popular pastime was watching television (3.82 hr/day) followed by listening to the radio (3.32 hr/day). The most prevalent disability was spinal cord injury (24%) followed by multiple sclerosis (16%), rheumatoid arthritis (10%) and cerebral palsy (10%). Approximately 20% of the survey subjects suffered from involuntary movement in their limbs. The daily living tasks section of the questionnaire was divided into four separate sub-sections:[4]

1. **Personal Hygiene Tasks.**
2. **Domestic Tasks.**
3. **Leisure/Recreational Tasks.**
4. **Working Environment Tasks.**

The survey subjects were asked about how well they could perform specific tasks under each of the above sub-sections. The percentage values of tasks that the survey subjects found difficult or impossible to do were calculated and tabulated, the top three tasks in each section were:

1.	**Washing Hair**	**(88%)**
	Rearranging Clothes after the toilet	**(80%)**
	Cleaning after the toilet	**(68%)**
2.	**Cooking**	**(84%)**
	Preparing Food	**(82%)**
	Filling the kettle	**(78%)**
3.	**Pick-up and throw objects**	**(58%)**
	Opening a wine bottle	**(54%)**
	Gardening	**(52%)**
4.	**Opening a letter**	**(48%)**
	Using a stapler	**(48%)**
	Posting a Letter	**(46%)**

Of the tasks that the survey subjects would most like to be able to do but could not - the highest were: reaching, stretching and gripping (44%), gardening (26%), reaching to the floor (24%), cooking (20%) and eating/feeding (18%). Percentages do not add up to 100 because the survey subjects had a choice of entering up to five tasks each. Finally, of the fifty survey subjects, 84% would consider buying a wheelchair mounted robotic arm if it could help them with some of the above tasks.

DISCUSSION

The above results provide a profile of the potential user of an electric wheelchair mounted robotic arm. The majority of survey subjects were living at home with support from their families but with no employment. This highlights the heavy burden placed upon the family of people with physical disability. The final design must therefore be able to operate within the confines of the home environment. By enabling some of the tasks listed above to be achieved, the system might eventually be used in a working environment.

CONCLUSIONS

An electric wheelchair mounted robotic arm shows great promise as an aid in performing daily living tasks for the severely disabled. several such systems have been developed in the past fifteen years, though none have reached the severely disabled community, due to some of the reasons mentioned earlier. If such a device could be produced at low cost (possibly utilising inexpensive pneumatic actuators) and of sufficient dexterity, it would undoubtedly have a worldwide market.

ACKNOWLEDGEMENTS

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Task-Oriented Control of a Robot Manipulator
Part I: The Concept

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ABSTRACT

This paper describes a novel control concept that allows a disabled user to continuously control the motion of a robot manipulator during the execution of a task. This is accomplished by partitioning the task into a sequence of simpler task oriented motions that are directly related to the motion of a virtual four bar linkage.

BACKGROUND

A robot manipulator, in the simplest sense, is a series of links joined by motors. The motors cause displacements to occur between the two links joined by that motor. In order to control the location of the end effector, or hand, of the robot, a displacement must be specified for each motor along the chain of links. Different sets of motor displacements will result in different locations of the hand. In the same way, one may also specify a set of velocities at each motor which will cause the hand to move at a prescribed velocity.

In order for a manipulator to be useful as an assistive device, it must be easy to control. The mental and physical load required to perform a task by controlling each motor displacement on a robot is too great, even for simple tasks. The alternative is to effect direct control over the characteristics of the task itself.

Controlling the location or velocity of the hand in task coordinates is difficult since typical coordinate systems by which the position of the hand is referenced (such as the Cartesian or Cylindrical systems) require complex mappings between the task coordinate frame and the motor displacement and speed parameters. Real time interactive computer control of the robot also requires an algorithm which can solve for the motor positions or speeds and communicate this solution to the robot in minimum time. The accuracy of the robot's positioning ability is directly related to the length of this time and is a function of the efficiency of the robot solution.

THE CONTROLLER

When a non-disabled person performs a manual task, he or she normally moves the hand towards a destination as a reference. For instance, in grooming one's hair, the person carries a comb towards the head as a destination, engages the comb with the hair, sweeps the comb through the hair over the surface of the head, retracts the comb, and repeats these simple motions until the task is complete. This may be followed by a motion to another destination, etc.

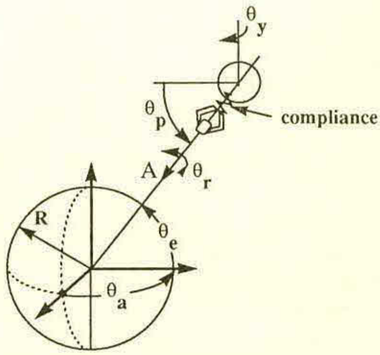

Figure 1: Hand of a Robot Manipulator and Reference Sphere.

In Task-Oriented Control of a robot manipulator, the user is given this same capability. Figure 1 shows the terminal device of a robot manipulator approaching an imaginary sphere as a destination. By controlling two analog inputs in the four modes described in Table 1, the user may continuously control the motion of the robot hand during the execution of the task.

Mode	Axis 1	Axis 2
Point	yaw	pitch
Approach	approach	roll
Adjust	radius	grip
Sweep	azimuth	elevation

Table 1: Modes of Task-Oriented Control

ACCOMPLISHING A TASK

To perform the grooming task described above, the user, with the comb in the grip of the terminal device, first selects the point mode.

Point Mode

In this mode, the user controls the pitch and yaw axes of the terminal device (θ_p and θ_y), and points toward the center of the head. He then selects the approach mode.

Approach Mode

The user then directs the comb to move along the approach vector (A) and may also change its orientation by controlling the roll angle (θ_r). Upon making contact with the head, the user switches to the adjust mode.

Adjust Mode

In this mode, the user adjusts the radius, R, of an imaginary reference sphere. The objective is to construct a sphere that approximates the shape of the head. Note that in this mode, the other axis controls the grip. Since the terminal device is already gripping the comb, this control is not used at this time.

Sweep Mode

Once the imaginary sphere has been constructed, the user controls the azimuth and elevation angles (θ_a and θ_e) of the hand as it "sweeps" over the surface of the sphere.

At this point, the user may select the approach mode, retract the comb, select sweep mode , go to a new location from which to insert the comb, etc. until the task is complete.

OTHER CONSIDERATIONS

For tasks that involve contact between the robot and the user, other considerations besides the motion itself must be addressed. To ensure the safety of the user, the contact forces that are generated may be monitored and controlled by the introduction of a compliance to the terminal device. In this way, the terminal device will accommodate the shape of the head without causing discomfort or detracting from the quality of the motion.

Task-Oriented Control allows for other variations. In the above case, the radius of the sphere, R, was positive, and the terminal device contacted the outside of the imaginary sphere. If R is negative, the terminal device will contact the inside of the sphere. If R is set to a large value, the spherical surface will approach a flat plane. Combinations of surfaces made up of spheres, flat planes, cylinders, etc. can be constructed by alternating the size and orientation of R during the motion.

VIRTUAL FOUR BAR LINKAGE

A significant simplification in the robot position and velocity equations is achieved by modelling the manipulator as a virtual four bar linkage in three dimensions. A robot manipulator may have up to six degrees of freedom, and therefore up to six motors must be controlled simultaneously to achieve a coordinated motion. In addition, the task itself, modelled as a sphere, is composed of three degrees of freedom. By coupling the robot and task geometries through the virtual four bar linkage, however, it can be shown that the resulting system has only three degrees of freedom. This means that the robot can be "driven" by the azimuth, elevation, and roll angles of the task and the robot joints will move accordingly.

Further, by constraining the hand to move towards the center of a sphere, and then to follow the contour of the sphere, the number of degrees of freedom that the user needs to control at any one time is reduced to two. The robot control equations, derived by considering the motion of the virtual four bar linkage, automatically solve for the required robot joint angles and velocities to accomplish the desired motion trajectories. This control scheme has been implemented on a commercial robot manipulator and the results are reported in [3].

CONCLUSIONS

The control concept described in this paper promises to offer a significant improvement in the control of a robot manipulator by a disabled user. By controlling two analog signals at a time, the user will be in complete control of the robot manipulator as it executes motions that are directly related to the task that he or she is attempting to perform. Further, the concept of the virtual four bar linkage yields a simplification in the control algorithm with a commensurate reduction in the computational burden on the control computer. This results in a minimum number of calculations to be performed by the control computer in real-time which should improve system performance.

ACKNOWLEDGEMENT

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TASK COMMAND LANGUAGE DEVELOPMENT FOR THE UT/HMMC ROBOTIC AID

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ABSTRACT

A method of control for a robotic manipulator for the handicapped is being developed which combines the strengths of the two traditional control methods, namely the Direct Control approach and the Workstation approach. The system operates in two modes: 'LEARN' and 'REPEAT.' LEARN mode allows for the user to define tasks as sequences of primitive level commands. The concept of modularity is implemented through three variable dependent primitive level commands. REPEAT mode allows for the re-execution of the tasks with either the predefined variables or new ones.

INTRODUCTION

An earlier phase of this project was the development of a voice controlled robotic workstation with the capacity of automated grasping. The control strategy was direct control with access to either world or joint coordinates (forward, back, down, elbow left etc.). This mode was chosen in order to allow the manipulator to operate within an unstructured environment. To grasp an object, the user is first required to move the robot's gripper to the general vicinity of the object by direct control. Once the gripper has been brought close to the object to be grasped, the automatic grasping routine is invoked through the GRASP command. The prototype was clinically tested [1] with a physically disabled population. It was found that direct control offers the flexibility required but imposes a heavy control burden on the user even with the provision of automated grasping. Other researchers [2] have investigated the workstation approach as a means of controlling robotic aids for the handicapped. The ease of use in such a system far surpasses the direct control method but does not offer the flexibility required. Our present efforts are directed at developing a system which incorporates the flexibility of direct control and the ease of use of a workstation into a single system.

DESIGN SPECIFICATION

In order to achieve a flexible system that would adapt to an unstructured environment as well as reduce the control burden on the user, a degree of artificial intelligence must be incorporated. Several issues have to be addressed to achieve the desired goal [3]. This phase of our project focuses on implementing the following features: (a) instructability, (b) repeatability, (c) adaptability, and (d) modularity.

Instructability and repeatability allow the user to define new tasks and repeat them at issue of a newly defined command. Adaptability allows for the definition of new objects and locations within the workspace and the continuous updating of an internal model that represents the environment. Modularity allows for the replacement of variables that constitute a learned task in order to perform a functionally different task but of similar primitive behaviour.

IMPLEMENTATION

Instructability and repeatability

This is implemented by allowing the user to guide the manipulator through a desired task using the primitive commands that are available. Once completed, the entire sequence of steps is saved in memory under a new task name. All variables (see modularity) that constitute the task are also saved. This procedure is possible when the manipulator is in LEARN mode. When a task has been instructed and saved, the user switches to REPEAT mode. In this mode, all previously tasks defined under LEARN mode can now be invoked. Such a method has also been proposed by other researchers [4].

Adaptability

An internal model that represents objects and locations, associated with their names is updated as the environment is altered. When an object or location is unknown to the system, the user switches to LEARN mode and guides the manipulator using direct control primitives to teach the necessary parameters.

Modularity

This has been achieved by implementing the following three variable dependent primitive commands :

GO TO location
MOVE object TO location
GET object

"object" and "location" are variables which can be defined by the user. The dependence of these primitives on object and location allow for the use of a previously defined task to be performed with different variables than the ones originally defining it. The following simple example serves as an illustration:

The user has defined the task DRINK as

MOVE milk TO mouth
WAIT
MOVE milk TO counter

The user then re-issues DRINK. The system responds by showing the sequence of primitives that constitute DRINK and the variables previously associated with it (milk, mouth, counter). At this point the user can either accept the default values or substitute "milk" with "pop" and "counter" with "shelf" as long as these variables have been taught using the appropriate provision. This illustrates the strength of this method in its ability to modularize tasks.

The system is currently being implemented on a U.M.I. RTX manipulator controlled by an IBM PC/AT compatible computer. A VOTAN speech recognition unit is provided for user input. Three infrared proximity sensors are mounted on the robot's gripper to provide the feedback required by the automatic grasping algorithm.

The user interface has been designed bearing in mind that the user is not necessarily technically versed. To this end, the following features are implemented:

(1) The screen displays are menu driven to help guide the user through the operations.

(2) The command language recognized by the voice unit is limited to the options available on each screen.

(3) The primitive commands are founded on natural language with the intention of helping the user in identifying with their function.

DISCUSSION

The combining of the workstation approach and the direct control approach allow for the customization of the robotic aid to suit the needs of the user. The workstation method, in principle, is a pre-programmed system that repeats pre-defined tasks in an efficient manner. This efficiency however is maintained at the expense of a rigidly constrained environment. The strength of this approach is incorporated into our system through the two modes: LEARN and REPEAT. Flexibility is maintained by allowing the user to define the environment and by keeping a constantly updated model of the environment.

FUTURE DIRECTIONS

Formal clinical evaluation of the system will be conducted upon completion of the aforementioned implementation. We anticipate a considerable reduction in the control burden on the user. To further allow for partial unsupervised operation of the system subsequent work will be directed towards the development of collision avoidance strategies using off-line 3-dimensional environmental modelling.

ACKNOWLEDGEMENTS

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SEATING IS A TEAM SPORT - A CASE STUDY

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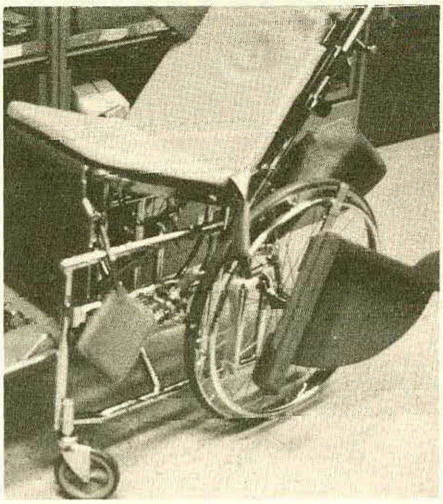
ABSTRACT
An athetoid, cerebral palsied client with fixed, severe deformities needed a custom contoured seating system. Skin over very bony prominences of the spine had been damaged repeatedly by an inappropriate planar system. A team consisting of parents, direct care providers, therapists and engineers collaborated to design, fabricate, adapt and apply a safe and appropriate seating system for this very difficult client. Once again, it was proved that development of seating demands active participation of everyone involved in service and care of the user.

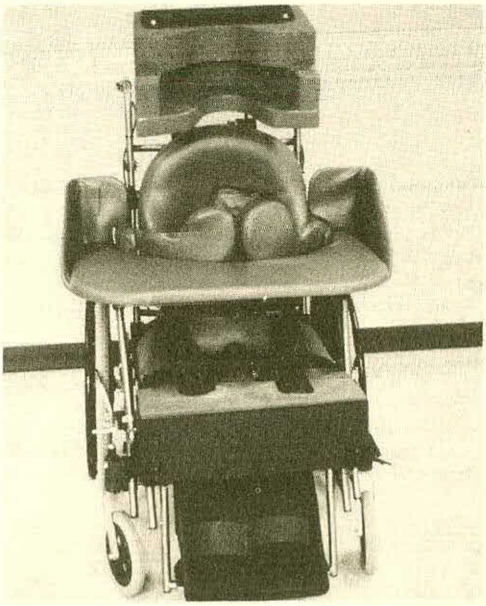
BACKGROUND

Blake Robison is a nineteen year old resident of a facility for developmentally disabled individuals. He is extremely spastic and very strong. He has severe scoliosis with bony prominences the size of golf balls on the spine. He is deaf and prone to repetitious, damaging motions of the head, hands, arms and legs.

An incredibly inappropriate planar or two-dimensional seating system was designed and fabricated for this young man about two years ago. The tight seat belt forced bony prominences on his back to "bottom out" through the padding on the hard back of that seating system. When the federal court gave permission, a most unique seating team was organized. The principals were a physical therapist from another state institution and a rehabilitation engineer from a private rehabilitation center. The physical therapist directed system design and fabrication. "Active participants" in the seating design, specification, and trial and fitting team included (1) the parents, (2) therapists from the home institution, (3) direct care personnel from the home institution and (4) therapists from the private rehabilitation center. This unique team developed a seating system that truly meets the functional and safety needs of the client.



Inappropriate Planar Seating System
Indentation in back caused by bony prominences



Team-Developed Contoured Seating System
"Soft spot" accommodated bony prominences

METHODS

Beadseat seat and back with "soft spot". A noted specialist was enaged to evaluate the client and to recommend a design approach. An Enduro Encore wheeled base was selected. The most difficult part of fabricating the seat and back was placing and holding the client in proper position during fitting. A section was cut out of the firm but resilient Beadseat back. Upholstery was applied by a vacuum-forming process permitting the vinyl upholstery to be drawn into the cutout. The pocket was layered with foam and Jay Flolite Pads. This produced a "soft spot" which would accommodate a golf ball!

Knee blocks. Knee blocks that compensated for leg length discrepancy and differing knee flexion angles were designed and fabricated. These were made from strong, laminated, closed-cell, light-weight foam. The knee cutouts were padded with Temperfoam. Stainless steel pipes telescoped into larger pipes secured to the undercarriage of the wheelchair.

Footrests and Armrests. Bucket type footrests with shims to compensate for leg length discrepancy were custom made from Kydex. Mounting position was critical because knee contractures cause the legs to extend under the seat. The Kydex armrests loop over the round armrests and a bolt secures the armrest to the wheelchair uprights. The assembly is well padded and closed at the rear to restrict range and prevent injury to the elbow.

Anterior supports. Kydex anterior pads provide substantial lateral support. These were contoured to the side and chest, padded with Temperfoam and covered with vinyl upholstery. They were mounted with Millers Swingaway and related hardware.

Headrest. A three-tiered headrest prevents ear damage caused by repetitious head turning. It is large to prevent Blake Robison from extending his head behind it. All corners are soft and rounded with convenient swingaway attachment. A "hand deflector" prevents pushing off with his hand.

Appropriately Seated Client - Happy Mother

RESULTS

Blake Robison sits comfortably and safely in his unique team-developed seating system. His lap belt fits loosely and comfortably. When he thrusts in full-body extension he inherently slips back into proper position. Parents and direct-care providers clearly understand function of all features of the chair. Development of this very successful seating system demonstrates that seating is definitely a team sport.

ACKNOWLEDGMENTS

Mr. and Mrs. Robison attended all the fittings and provided invaluable design suggestions. Hissom Memorial Center direct-care personnel provided key design features that enhance transfer and assembly of the chair. Oklahoma Department of Human Services made personnel available. The Mervin Bovaird Foundation and the Occidental Petroleum Company Foundation provided basic financial support. The Rehabilitation Engineering Department of the University of Tennessee - Memphis provided technical support essential to the success of this program.

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DESIGN PROCESS FOR HEALTH CARE PRODUCTS

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ABSTRACT

There are literally thousands of products manufactured for the health care industry. How did these products evolve?

The purpose of this paper is to explain the stages of the product design process and to provide some insight into how health care products are designed and developed.

WHAT ARE THE STAGES OF DESIGN ?

Product design is a complex, decision making process which develope the basic, tangible component parts required to accomplish a product's intended results. Although the stages of design listed below have a natural chronological order of completion, in practice it is often necessary to return to earlier stages when technical, economical, or other problems are encountered during design process.

1) Establish Product Features
It is necessary to first establish the primary "must have" features of the product, then determine the secondary or optional product features. Product features and their relative importance should be established because some features are achievable but at the expense of another feature. The initial listing of product features starts out as a "wish list" and includes some features that may later be found unfeasible as the design progesses.

2) Establish Design Parameters
The next step involves establishing design parameters such as overall dimensions, sizes, and performance specifications. As the product design progresses, changes to the parameters may be required if they are also found technically or economically unfeasible.

3) Establish Major Components
Major components critical to the success of a product should be established at this stage. Engineering principles are often used to help determine strength requirements and thus sizes and materials of components. A decision must be made whether to: a) share major components used the company's other product lines, b) use commercially avaiable "off-the-shelf" components, c) develop a component to the required specifications. Major components such as motors and controllers are major products themselves and require long lead times to develop if suitable motors and controllers are not readily available.

4) Construct Design Drawings
Design drawings are generally large, accurately scaled drawings which designers use to visualizing ideas and solutions. Instead of trying to design the whole product at one time, designers isolate features to break-up the problem into smaller, more manageable problems. Once a proposed solution to a feature has been drawn, it is then necessary to coordinate the design of that feature with other aspects of the design.

5) Construct Prototype(s)
Prototype drawings are constructed with information from the design drawings. The prototype drawings or sketches include information such as part dimensions and material specifications which are necessary for a machine operator to produce the prototype parts. Design deficiences such as assembly problems, are sometimes revealed during prototype construction and must be corrected before production.

Product features are often added, deleted or changed based on suggestions and feedback from prototype field tests. Several generations of prototypes are usually required before reaching the final production design.

6) Complete Production Design
Production drawings are required to manufacture the product in production quantities. Components may need to be redesigned if found to be economically unfeasible for manufacturing. Most prototype drawings require final revisions before they can be used as production drawings.

NEW PRODUCT CONSIDERATIONS

Accurate information, interpretation, and planning improve the chances of developing a successful product. Some company concerns that must be addressed throughout the design process are listed below:

1) Management/Finance Considerations
- What capital investment is required?
- What is the return on investment and pay back period?
- What will be the inventory requirements?
- What will be the cost of product liability insurance?
- What will it cost for research and development?
- How accurate is the information and and sales forecasts?

2) Marketing/Sales Considerations
- Who will buy the product?
- What are the realistic sale forecasts?
- How stable or competitive is the market?
- What should the selling price be set at?
- How much will funding agencies subsidize or reimburse buyers?
- Can existing product be improved to meet needs?
- Will new product cut into sales of existing products? maximum sales effect?
- Where should the product be positioned? Deluxe or economy?

3) Engineering/Production Considerations
- What features are required?
- What are their relative importance?
- What are the design parameters?
- Can it be done? Technically?
- Is there enough in-house technical expertise?
- What manufacturing cost is acceptable?
- Does the company have the manufacturing capacity for new product?
- What is the annual volume anticipated?
- Are there governing industry standards or regulations?

DESIGN CONFLICTS

A designer makes many decision as a design progresses and must choose the best compromise between conflicting concerns. Decisions must be made to determine the most successful compromise when two or more product features are not compatible. Listed below are some common design conflicts which affect product design. Although the design conflicts have been grouped as pairs, decisions constantly arise where several conflicts must be considered at the same time. For example, modularity, adjustability, and simplicity are three concerns which affect each other.

a) Maneauverability vs Stability
b) Lightweight vs Strength
c) Portability vs Rigidity
d) Aesthetics vs Function
e) Power vs Range
f) Gradeability vs Speed
g) Redundancy (safety) vs Optimization
h) Modularity vs Customization
i) Serviceability vs Compactness
j) Fabrication vs Tooling methods
k) Comfort vs Function
l) Ground clearance vs Seat height
m) Adjustability vs Simplicity
n) Outdoor vs Indoor applications
o) High quality vs Low quality
p) Factory assembled vs Dealer assembled
q) Optional vs Standard features
r) Factory vs Dealer installed options
s) Manufacturing costs vs Precision assembly
t) Engineering achievments vs Humanitarium concerns
u) Perfection vs Deadlines

SUMMARY

There are many technical and business challenges faced by designers of health care products. Designers are pressed to develope better products that do everything, fit everybody, and are aesthetically pleasing, while still affordable.

Innovative and technologically advanced products are hindered by many factors. The relatively low sales volumes for many health care products do not give the same economies of scale afforded to large consumer industries.

Successful product designers must have a good understanding of engineering and business principles in order to objectively consider all factors before making design decisions. The needs of the end user, care givers, therapists, DME dealers must be understood in order to design a commercially successful product. Although management is ultimately responsible for the success of a company's products, it is the designer who must solve technical design problems which have business implications.

ACKNOWLEDGEMENTS

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The Smart Wheelchair: A Discussion of the Promises and Pitfalls

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ABSTRACT

The application of robotics technologies to improve the safety and ease of operation of powered wheelchairs could offer the possibility of independent mobility to large numbers of severely disabled and multiply handicapped people. This paper discusses some of the controversial issues associated with the concept and includes a brief outline of preliminary collaborative work towards the development of such a "smart" wheelchair system.

INTRODUCTION

Establishing independent mobility provides disabled individuals with a high degree of self esteem (1). Perhaps more than any other physical deficit, loss of mobility is a constant reminder of an individual's dependence. Although present day powered wheelchairs provide this important freedom for many people, clinicians are seeing growing numbers of clients for whom the conventional powered wheelchair cannot provide safe, independent mobility (2). These people are likely to be developmentally disabled, visually impaired, cognitively impaired, severely physically disabled, or have a combination of these disabilities. Over the past decade, several researchers have suggested the application of new robotics technologies to the creation of a "smart" wheelchair (3,4,5), that could overcome many of these mobility problems. The smart wheelchair would combine a variety of sensors with powerful computers, such that it would be inherently safe, easier to operate, and virtually crash-proof. It would be able to avoid collisions, follow walls, find and negotiate passage through doorways, and avoid hazards such as open stairways. Having explored the possibility of a smart wheelchair, the authors discovered a surprising number of interesting issues, both pro and con, that the concept raises. We feel these issues are sufficiently serious that they need to be considered before more devices are built.

Manufacturers already have made significant improvements to powered mobility aids. Microprocessor-based controllers have made powered wheelchairs easier to operate, with features like acceleration and speed limiting, automatic braking, dynamic braking, velocity ("cruise") control, and directional control over hilly terrain. As well, these controllers have permitted interchangeable user interfaces and automatic battery monitoring. While these improvements are welcome, there are still a number of areas in powered mobility where further improvements are needed. For example, since mobility is so important to a mobility-impaired person, the reliability and battery capacity of these systems needs to be even higher than what is currently available. Obviously the deficiencies in current powered mobility systems pose different degrees of inconvenience to different disability groups. For some candidates, powered mobility will continue to be unsafe and inappropriate until smart systems are developed.

ISSUES

Reliability

A smart wheelchair could provide independent mobility to persons who were previously inappropriate candidates for powered mobility. But then a blind person, for example, would become entirely dependent for their personal safety on the technology that gives them independent mobility. This places great emphasis on the development of sensor technologies which are effective in detecting a variety of obstacles or dangers in widely differing environments. It also places great emphasis on the reliability of these sensors.

People are justifiably suspicious of the reliability of commercial machines (e.g. photocopiers). This is to be expected, because commercial products are carefully designed to meet an acceptable degree of reliability, and no more. Increased reliability is achieved usually by selecting higher quality materials and components and by carefully monitoring manufacturing practices, all of which increase costs. Wheelchairs are commercial products, also, and must strike the right balance between cost and reliability. Reliability is also dependent on a system's complexity. Since the smart wheelchair will have greater complexity than a conventional wheelchair, the reliability of all of its sensors, controllers, and circuitry must be exceptionally high. Can this be achieved without pushing the cost out of reach?

Safety

Whereas reliability of a system is largely dependent on its manufacture, safety is more a result of careful and thorough design. Designing for safety means taking into account the fact that no component or subsystem is 100% reliable. For the smart wheelchair, this means the development of sensors which can sense the difference between useful signals, ambient noise, and faults in their own internal circuitry. Also at issue here is the safe operation of the underlying motor controllers. For instance, techniques must be devised to prevent the chair from going out of control due to component malfunctions. While many safety requirements can be achieved through clever design, the conventional approach is to add extra circuitry to monitor the proper operation of all the other circuitry. As with the question of reliability, this will add to the overall system cost.

Appropriate User Interface

While safety and reliability are essential for a smart wheelchair, the most critical aspect of the design will be the user interface. The question to be resolved is, who is in control, the human or the machine? There is plenty of evidence from psychological studies to confirm the importance of the human user being in control (6,7). The degree of control persons have over their lives and life's activities directly influences their self-image, their sense of independence, their ability to learn, remember, plan, and organize their lives. It is imperative then, that the smart wheelchair concept not degenerate into a device which is used simply to transport a "body" from one point to another. The control interface must make the user feel totally in control of the smart wheelchair, no matter how little physical control the user can exert over the device.

Ideally, the smart wheelchair would become an extension of the operator's senses, providing him with additional information about the environment upon which to make decisions. The problem is to feed back the sensor data quickly enough for the operator to consider the information and make the right decision. This must be done before the vehicle hits an obstacle, for example! The simple solution here is to feed the sensor data to the computer on the smart wheelchair and have it decide what to do. Since this can be done so much faster, the vehicle will have plenty of time to stop before hitting a detected obstacle. The hazard with this "reflex" approach is that the human operator has been shut out of the control loop and the smart wheelchair takes on the appearance of an autonomous mobile robot. An appropriate user interface, therefore, must be one that shares control between the human and the machine, so that a synergism is established. That is, together they achieve safer and more effective control than either could alone.

This sharing of control is what the smart wheelchair is all about. While the machine takes over as many low-level chores as possible, the user still makes the supervisory decisions. Analogies to an aircraft automatic pilot or an automobile automatic transmission are appropriate and worth the comparison. These systems reduce the pilot's or driver's effort and the need for constant attention, permitting him to attend to more important matters. With respect to the automatic transmission, it is true that better control of a car is possible if the gears are operated manually by an skilled person. Note that many people are willing to pay the premium price for the convenience of an automatic transmission. In other words they feel that it is cost/beneficial.

Impact on Development

There is concern that a disabled child using a smart wheelchair might never outgrow his dependency on it. For example, if the chair always prevented collisions, the child might never learn to adjust speed and steering on his own. On the other hand, if the user interface were adaptable, taking action only when necessary, then perhaps the smart wheelchair would function as an aid to development (5). Another argument recalls the analogy to the automatic transmission. We are all dependent in various degrees on technological devices. For most people not knowing how to shift gears manually doesn't matter — getting where they want to go is what is important. Still, there are some who feel it is necessary to prove themselves by operating the gears (i.e. they need the image of being in greater control). Clinical studies will be required to clear up this dispute: does the smart wheelchair ultimately foster greater dependence or independence?

AREAS OF EMPHASIS

Key concerns of our group are the safety and reliability of the smart wheelchair. Below is a list of research areas we consider of importance.

1. Obstacle detection and speed curtailment in "cluttered" environments.
2. Navigational features such as wall following (to improve straight line travel), doorway negotiation and position location within an institution (so that the user or the staff know where the wheelchair is in the building).
3. Stairwell detection and avoidance. One of the major sites of wheelchair accidents is the open stairwell (8).
4. Automatic system safety checks. Sensors, servos, tachometers, motors, motor controllers, and user interfaces all would be tested regularly during the operation of the smart wheelchair.
5. Multiple sensors using different, complementary techniques to measure the distance to objects in the environment (9).
6. User interface. A means to select from a range of possible control devices, with alternate ways to feed back (i.e. display) sensor data to operators who have different types of disabilities, including sensory disabilities.

Currently under development are a distributed sensor system for the smart wheelchair and an interface for the Everest & Jennings Lancer wheelchair.

We expect that wheelchair users and prescribers will have strong opinions regarding the possibilities of a smart wheelchair. Hence we are undertaking a survey of these groups to help determine priorities for the development of smarter, safer wheelchairs. Also, the survey will attempt to identify the most appropriate disability group towards whom to target the smart wheelchair development work. The survey will be completed by September, 1990.

CONCLUSIONS

Developing a functional smart wheelchair system, and proving it's clinical success, will require a large effort on the part of many people. The authors have agreed to collaborate with each other to investigate some of the technical and clinical issues raised in this paper. We invite other research groups to join with us in addressing these important issues.

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Third World Wheelchair Manufacture: Will It Ever Meet the Need?

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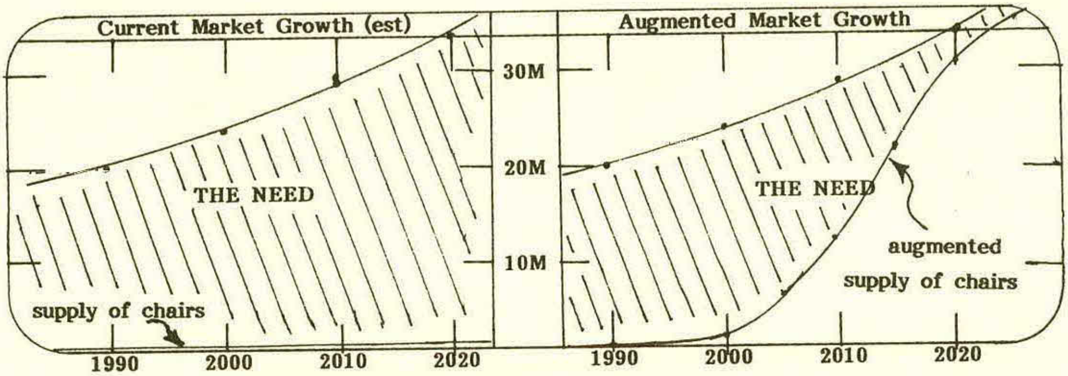
ABSTRACT
Fewer than one percent of the estimated 20 million potential wheelchair riders in the Third World are known to own a wheelchair today. At the present rate of growth in the Third World wheelchair market, most potential riders will not get a wheelchair during their lifetime. This paper explores the level of resources that will be needed if a worldwide effort to provide wheelchairs in the Third World is to succeed.

MEETING THE NEED: WHERE TO START?
Over 1 in 200 U.S. citizens uses a wheelchair; a larger percentage of people are likely to need wheelchairs in countries where polio and preventable amputations are still common. Over 4 billion people live in the less developed countries; easily 20 million of them need wheelchairs. That number will rise with expanding population to 24 million by the year 2000.



RAPID CHANGE IS NEEDED
FOR APPROPRIATE CHAIRS TO BECOME GENERALLY AVAILABLE IN THIS LIFETIME

GIFTS VERSUS INDEPENDENCE
Imported wheelchairs are not likely to satisfy the need of the Third World. Not only is the initial cost too high; repair parts must come from the manufacturer at a cost far in excess of the average user's ability to pay.

Even gifts of foreign wheelchairs can have a detrimental long-term effect. The local manufacture of highly appropriate all-purpose wheelchairs was going well in Malawi in the mid-80's until a gift of several hundred oversize, overweight hospital-type chairs arrived from a European donor. The need for minimal mobility was temporarily satisfied, but the local wheelchair manufacturer was put out of business due to the temporary lack of demand. The imported chairs have broken down quickly; locally made chairs are no longer available to replace them.

Hopefully wheelchair manufacture can be re-started in Malawi. A foreign gift of start-up capital to local manufacturers should result in far more chairs than could be provided by another shipment of imports. Foreign funds could also be well used to establish consumer credit funds for the purchase of wheelchairs or to provide matching grants directly to consumers.

1 out of 5 U.S. wheelchair riders is of working age or younger; in developing countries most of the chairs manufactured sofar have gone to riders from this age group. A reasonable initial goal might be to reach a Worldwide production level that would supply chairs for the working age riders by the end of the century. A production rate of 1 million chairs per year could come close to filling this need, assuming each chair continues to function for 5 years (the U.S. average).

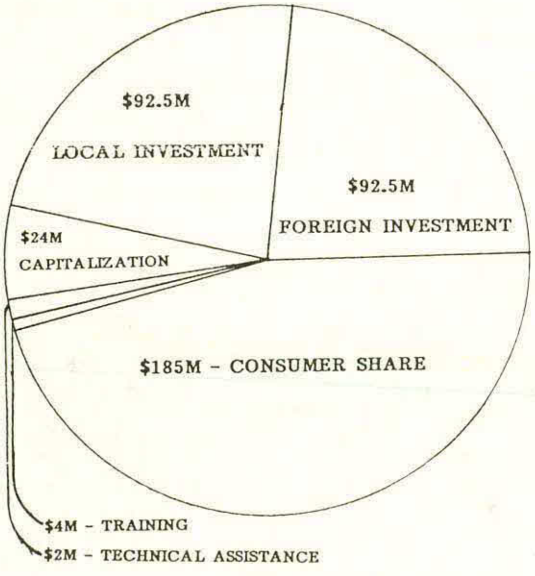
THE CURRENT MARKETPLACE
Current wheelchair production in India is less than 20,000 units per year, according to India's leading producer. Wheelchairs are reported to be less numerous in China and most parts of Africa than in India. While per capita wheelchair use in several Latin American countries is higher, their annual production still totals no more than several thousand chairs.

An incomplete survey of manufacturers' estimates has indicated that the total Third World wheelchair production may be in the neighborhood of 50,000 units per year. Small as this industry is, its growth is still impressive. Starting from virtually nothing in the 50's, the growth rate in chairs produced is about 10% per year, or over twice that of the

U.S. wheelchair industry. Even if this 10% rate of growth continues, the industry will not make enough chairs even to match the growth in population until late in the next century.

To make more significant progress a much faster rate of growth is needed. To meet the bulk of the total need for wheelchairs in the next 30 years, for example, a growth rate of 30% per year would be required. Maintaining this extraordinary growth rate would require extensive training of lead mechanics, capitalization of both small and large wheelchair shops, matching grants and credit funds for consumers, a continuous program of technical assistance to the manufacturers, and, extensive development of rehabilitation.

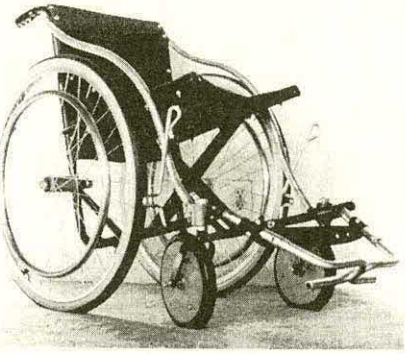
A TEN YEAR START UP PLAN-$400 MILLION



WHEELS FOR RIDERS OF WORKING AGE BY 2001?

An aggressive program of training, capitalization, partially subsidized purchase and consumer credit might actually make it happen.

THE ULTIMATE PEACE DIVIDEND
Making wheelchairs available to all potential riders will not be cheap - the cost could easily reach $400 million over the next ten years. But much of this investment would come from - and quickly be returned to - the local economies. And the recent reduction in World tensions could free up enough capital in the donor countries to prime the pump of one of today's most significant social metamorphoses - the Disability Rights Movement.



THE TORBELLINO -
LESS THAN $100 IN SRI LANKA

HISTORY OF THE TORBELLINO WHEELCHAIR
The original Torbellino was developed in Nicaragua and the Philippines between 1980 and 1985 under contract to Appropriate Technology International. The project is now located at the Wheeled Mobility Center of SFSU. Using the instruction manual Independence through Mobility (A.T.I., 1985) over 100 mechanics have been trained in the manufacture of the Torbellino, and fabrication is taking place at 25 shops in 18 countries worldwide. The chair is designed to be as light as some of the best ultralights, and can be manufactured in large or small shops with an investment, including start-up, of about $2000 per skilled worker.

Goals of the Wheeled Mobility Center
- Work with wheelchair rider/builders in the Third World to lower cost and raise quality of wheelchairs.
- Train Third World mechanics and assist them in setting up new wheelchair production shops.
- Raise riders' awareness of health care, independent living, and disability rights.
- Establish a network of expert trainers to provide technical assistance and transfer technology worldwide.
- Perform strength and durability testing of chairs made in Third World shops.
- Assist organizations active in developing the Third World wheelchair industry to:
  - Identify organizations to manufacture wheelchairs
  - Make training, business planning, sample wheelchairs, and tooling available

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Assessment and Training of Persons with Cognitive Disabilities: Computer Job Skills Preparation

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Abstract

The *COMPETE* project is funded by the US Department of Education's Postsecondary Education Program for Handicapped Persons, Nondirected Demonstration. The *COMPETE* project has developed and is implementing a model program of cooperative service delivery that includes the NYS Office of Vocational Rehabilitation, the Western New York Independent Living Center, the NYS Office of Mental Retardation and Developmental Disabilities, and the University at Buffalo. The model program is called *COMPETE* which is an acronym for Computer Preparation: Evaluation, Training, and Employment. *COMPETE* serves individuals with cognitive disabilities, including traumatic brain injury, learning disabilities, and mental retardation.

COMPETE has assembled an interdisciplinary evaluation and program planning team that includes a vocational counselor, occupational therapist, rehabilitation engineer, physical educator, and nutritionist. This team assesses vocational and other community integration needs. Curriculum and training materials focus on three levels of computer skills from basic keyboarding and data entry (Level 1) through advanced word processing and computer communications (Level 3). Assistive devices and special adaptations are provided as needed. The WNY Independent Living Center assists with community integration needs, including transportation and housing. The Western New York Employer Task Force for Individuals Disadvantaged or Disabled assists in identifying appropriate jobs and adaptations to the work environment for the special needs of the job trainees. We are accepting 8 job trainees in the first year, and fifteen in each of Years 2 and 3 of this three year project. This project is housed at the University at Buffalo, within the Center for Therapeutic Applications of Technology.

Faculty at the University of Buffalo established the Center for Therapeutic Applications of Technology (CTAT) with the major goal of increasing public access to information about assistive technology. To this end, CTAT is focused on comparative evaluations of assistive and therapeutic technology, especially technology that improves a person's performance of educational or vocational tasks.

1. **Participant Identification**: This is done by the NYS OMRDD, the NYS OVR and the WNY Independent Living Center. Potential participants must: (1) be between the ages of 15 and 30 years, (2) be mentally retarded, have a learning disability, or have suffered a traumatic brain injury (individuals with physical disabilities as a second disability will also receive training), (3) be unemployed, (4) have an interest in being competitively employed in a job relating to information processing (computer data entry and/or word processing), (5) have completed or left a secondary school program.

2. Individualized Evaluations: Each participant receives, an initial evaluation that includes a battery of tests: Academic/Cognitive (Communication, Math, Learning Style), Functional Skills (Community, Office Environment, Keyboarding/Computer Aptitude, Domestic), Sensory, and Interpersonal (Behavioral, and Physical).

Working with small groups of COMPETE participants, the project provides computer training consisting of:

Level I

(1) basic components of computer system
(2) keyboarding
(3) data entry

Level II

(1) data base management
(2) basic word processing

Level III

(1) intermediate to advanced word processing
(2) communications (modem and fax)

Training Placement follows the Individualized Evaluation. A key component is simulation of the work environment of targeted jobs. COMPETE participants may be placed after completion of any level, and if additional competencies are indicated participants may move through several levels of computer training before identifying and securing full time placement, although temporary placement is sought at each training level to reinforce the acquired skills. Program training varies from two months to a year.

Training consists of a combination of:

(1) teacher – instructed laboratory sessions, with participants working on computers (1 computer/student)

(2) open computer laboratory time, to practice assignments, with assistance available

(3) job apprenticeship in the Center for Therapeutic Applications of Technology at the University at Buffalo (assisting in real computer tasks, under supervision).

When needed, individuals are evaluated for the use of special equipment, such as an adapted keyboard, or other alternate input devices. COMPETE participants are able to view, prior to placement, videotapes of the competitive employment positions under consideration. Job visits prior to placement are also conducted.

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TECHNOLOGY TRANSFER TO THE PA OFFICE OF VOCATIONAL REHABILITATION

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Robert Barry, Bell of PA Fellow, Penn State University
Terry Williard, Rehabilitation Specialist, PA Office of Vocational Rehabilitation

Introduction

As any major government agency might, the Pennsylvania Office of Vocational Rehabilitation feels a need to keep up with fast moving technologies both for client service and for professional productivity. This is all the more true in Pennsylvania, because particular pains are taken to place severely handicapped clients in productive employ, and indeed some success has been attained.

To promote technology transfer from industry and from academe, a Commission on Advanced Technology was formed in 1986, drawing on senior managers from high tech industry in the state, from academic leaders in rehabilitation, and from the care provider community. There has been remarkably little change in this group since its inception. The Commission meets quarterly.

Not all of the members were familiar with VR issues, so the Commission has met at various offices and facilities of VR to meet staff, see what is done, learn what the issues are, and in a visit to Edinboro University where some 300 students with handicaps are pursuing higher education, to meet with VR clients as well.

It was quickly learned that while the VR issues are special in certain restricted ways, many of the questions of staying up to date are common between government and industry, and certainly in the case of professional productivity, the issues are practically the same. Therefore, there was some reason to believe that VR could learn from industrial experience.

It was learned, again rather quickly, that the Commission could not do some things. It could not look at a particular case, offer high tech solutions, and improve the results for particular clients; the make up of the Commission and the format of the meetings just do not lend themselves to such.

However, the Commission is able to examine general issues.

Technology Transfer Issues in VR

Will present Pennsylvania law restrict home based employment of handicapped persons who might be able to do computer based work even though home bound or even bed fast?

It turns out that in Pennsylvania, "cottage industry" law applies only to the textile industry and to food processing, so most coputer based work is allowed.

What industry standards are lacking in vocational rehabilitation?

Presently, the Commission feels that standards are lacking in certification of rehabilitation engineering care providers and in certain technical areas such as synthetic speech. These matters are familiar to RESNA members, and perhaps RESNA will be the vehicle for providing such standards in the future.

Are physically handicapped persons being trained for the right sorts of jobs?

A number of clients are being taught to operate word processors. That is modern, but some of these clients have poor hand dexterity and will never be competitive with an able bodied typist. It would be better to teach them desk top publishing or computer aided drafting, which are better jobs in the first place and less dependent upon hand and finger skills. The Commission is making a list of modern industry positions which use mental skill more than dexterity, so that clients can be targeted to jobs where they have a reasonable chance of being competitive with the able bodied.

Half of the VR clients have mental rather than physical disabilities. Are these clients being trained for the right sorts of jobs?

The Commission has found that the Commission members can talk their way into the executive offices of many companies and ask the executive management if they would employ persons who have mental handicaps, (the answer is almost always yes), and what kind of jobs are going to be available. The results to date are that employment opportunities have been found faster than the candidates can be trained to fill them. This provides very specific training targets with good prospect of initial employment.

How can technology be transferred to the VR staff?

The Commission has settled on a series of one-day seminars in various parts of the state, to which VR management and professional staff are invited. The seminars consist of a series of persentations, some by Commission members and some by others, on topics of current interest. While the seminars vary somewhat over time, a typical seminar would include the following topics:

1. Chair seating technology.

2. Augmentative communication.

3. A preview of future technologies, such as cognitive orthotics.

4. Office technology and productivity.

These seminars are now being supplemented by printed material including typical cases, forms, references, and so on. We look forward to having additional material on audio tape and video tape.

VR staff have responded enthusiastically to these seminars, because they know themselves that a lot is going on, they want to know about it, but they need a mechanism by which to learn. These seminars seem to help.

The Commission has served its purpose in Pennsylvania. Along with internal training and related activities, the Commission has helped keep the Pennsylvania OVR moving with the technology flow and maybe even gaining on it.

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Linking Architecture and Technology - Increasing Employability of Persons With Physical Disabilities

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Abstract
This model project, Adapting Environment for Work Placement, represents a comprehensive approach for resolving problems in job placement service through architectural assessment and adaptive technology. This work placement program links potential physically disabled employees with employers willing to explore technology based support to accommodate the individual with physical disabilities. The link between the potential physically disabled employees and the employers is adapting the work space environment, work station, work tasks and the assistive devices needed to complete the work tasks. Using this approach individuals with physically disabilities can return to the work force.

Introduction

This paper describes the first year of a two year model project. This project demonstrates how to increase employability of person with physical, sensory, or communication disabilities. The major first year tasks of this project are: 1) Introducing employers to the rehabilitation counselors who have the task of locating jobs for persons with physical disabilities, 2) Performing assessments by a rehabilitation team, and 3) Providing work simulation activities with the simulated work station.

The three major tasks for the first year of this model project are:

1) Introducing employers to the rehabilitation counselors.

This phase of the project introduces potential employers to rehabilitation counselors and placement service agencies. The employers have tasks that through architectural changes to the building and work station and use of adaptive equipment could be performed by a persons with physical disabilities. The counselors and agencies are aware of persons who would like to work but due to disability are unable to perform work tasks. During these introductions there will be presentations which provide information to the employers about the incentive for hiring persons with physically disabilities, the potential value of such employees and the project's ability to implement cost-effective placements.

2) Performing assessments by the rehabilitation team.

The rehabilitation team consists of an architect, a rehabilitation engineer, an occupational therapist, a speech pathologist, and a social worker. This team of experts assesses the potential employees, makes recommendations to enable independence at work tasks, and makes changes as needed at the simulated work station.
The assessments performed by the rehabilitation team are in two parts. The first is an evaluation of the physical, sensory, functional, and motivational status of the clients. The second part is an evaluation of mobility, architectural barriers in the building where the person will be employed, task performance in the work environment, and the ability to operate computerized adaptive equipment.

3) Simulated work activities with the simulated work station.

This third task centers around the laboratory based simulated work station. This work station serves three purposes. First evaluations are conducted here to assess clients ability to function in the work environment and recommendations are made to allow the client to function independently. Second, work activities are simulated to allow the client to practice work skills. Third it serves as a demonstration unit to employers. Used as a demonstration unit, the effectiveness of the work station to provide the link between the physically disabled person and employment opportunities is effectively shown.

Conclusions

Successful work placement of persons with physically disabilities often requires special modification within the employer's work environment. Architectural and adaptive technology together provide the means to adjust to the needs of persons with disabilities into the work force.

Acknowledgements

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REHABILITATION ENGINEERING: WHO PAYS FOR IT?

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ABSTRACT
Rehabilitation engineering has become an important part of the rehabilitation process, especially for people with severe disabilities. There are thousands of off-the-shelf products that may offer solutions to an individual's needs. For example, ABLEDATA, Newington, CT. is continuously updating its database with more than 15,000 products commercially available from over 1,900 manufacturers. Occasionally these products may require modifications to optimize one's capabilities. In some special cases, one may have to design and fabricate a device where nothing exists in the marketplace. The critical question "Who pays for these products and services?" is answered in this paper through a case study.

REHABILITATION ENGINEERING SOURCES
In response to Congressional mandate, GSA (General Services Administration) adopted a policy for all Federal agencies which implements Public Law 99-506, Section 508 (29 USC 794d) regarding electronic office equipment accessibility (Brummel 1989). Some federal government employees with disabilities will receive accommodation-related software and hardware, as well as additional training to use these products.

NARIC's recent newsletter indicates the most important step for obtaining selected aids and devices is locating appropriate funding sources (NARIC Quarterly 1989):

Medically-Related Sources
- Insurance company and industry
- Private health insurance
- Medicaid and Medicare
- State Worker's Compensation
- Veterans Admin. Medical Center

Employment-Related Sources
- State Voc. Rehabilitation
- PASS (Plan to Achieve Self Support) Social Security Adm.
- Special Education Program
- Revolving loan fund through a bond referendum

Other Sources
- Corporate foundation
- Private foundation
- Health organizations (Multiple Sclerosis Society, Muscular Dystrophy Assoc., United Cerebral Palsy, Easter Seal, etc.)
- Loan Closets/Library
- Civic organization (Rotary, Kiwanis, Lions, etc.)
- Media (TV/radio)

The following case study demonstrates how Stephen obtained various engineering resources:

Case Study

Stephen Baily, a 22-year old man with Muscular Dystrophy, holds an AA degree in Computer Aided Drafting (CAD) from Essex Community College, Baltimore County, MD., where he helped develop a specialized work station that allows him to control the computer hardware and software. After graduation, he joined the Alliance. Through the Job Club, he was able to put together a resume and practice job seeking skills. Alliance staff members assessed his home as a potential job contracting site. With this information, the Alliance was able to secure a CAD contract for Stephen with Spears & Votta for twenty hours a week. Subsequently, Stephen obtained a second contract with EIL Instruments. He is currently performing both contracts in his home for $7.00 per hour. (Figure 1).

This success is the result of cooperation between Stephen, his family, the Department of Vocational Rehabilitation (who funded a work station), Volunteers for Medical Engineering (who donated all necessary CAD equipment) and the Alliance (who provided job placement assistance and rehabilitation technology services, including a custom wheelchair tray, and angled typing sticks). A wheelchair lift to transport him to and from his basement office, and a hoyer lift to transfer him to and from bed, were also provided. Bathroom modifications and an outside ramp have increased Stephen's independence considerably. Table 1 details all rehabilitation engineering solutions and their sources.

SUMMARY

The main point is that Stephen did not receive $42,950 worth of products in one day, but over a period of 11 years. This was possible due to Stephen's strong belief that he could become independent, coupled with the Alliance's coordinated effort of engineering services.

Technology-Related Assistance for Individuals with Disabilities Act (P.L. 100-407) of 1988 may create a significant impact on assessment and delivery of devices. There are nine states funded by the NIDRR (National Institute on Disability and Rehabilitation Research) of the U.S. Dept. of Education, to create, develop, implement and support a statewide system for delivery of technological assistance to enhance the quality of life for people with disabilities. We hope these State programs will identify funding mechanisms to provide engineering services that will optimize the capabilities of people with disabilities.

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ADDRESS

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Figure 1: Stephen's Home Based Work Site

EQUIPMENT/MODIFICATION	WHO PAYS FOR IT	DATE PROVIDED	COST
Medical Related Resources:			
Wooden Ramp	MD. Trans. Authority	1978	$ 800
Chevy Van 1974 (Used)	Stephen's Family (SF)	1978	$ 4,000
Van Modifications	Hlth.Ins.(80%)-SF(20%)	1978	$ 4,000
Portable Ramp	Hlth.Ins.(80%)-SF(20%)	1982	$ 200
Hydraulic Tub Lift	Musc. Dys. Assoc. (MDA)	1978	$ 500
Hydraulic Hoyer Lift	MDA (Loan Closet)	1979	$ 600
Powered Wheelchair	Hlth.Ins.(80%)-SF(20%)	1984	$ 6,000
Powered Bed	Hlth.Ins.(80%)-SF(20%)	1985	$ 1,300
Hand held shower, seating cushion, clothing, etc.	MDA, SF, Soc. Sec. Adm.	1988	$ 1,000
Employment Related Resources:			
Powered Lift to access basement	Volunteer Medical Engr. (VME Loan Closet)	1988	$ 4,000
Installation of Lift	Dept.Of Voc.Rehab.(DVR)	1988	$ 8,000
Basement office with	Stephen's Family	1988	$ 2,500
Computer Aided Drafting(CAD)			
Pers. Computer w/monitor	VME Loan Closet	1988	$ 6,000
Digitizer	DVR	1988	$ 400
Auto CAD Software	VME Loan Closet	1988	$ 2,600
Other Software	VME Loan Closet	1988	$ 200
Graphic Card	VME Loan Closet	1988	$ 550
Pointers & lap board	Alliance, Inc.	1988	$ 300
		11 YRS.	$42,950

Table 1: WHEN SOMEONE PAYS FOR EQUIPMENT/MODIFICATIONS

A System of Assistive Technology Service Delivery for Persons With Visual Impairments

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Abstract

The New York State Commission for the Blind and Visually Handicapped (CBVH) has established a system of service delivery in assistive technology that includes eight regional *Adaptive Technology Assessment and Training Centers* for persons with low vision or who are blind. The bidding process was initiated in August, 1989, and the Centers were established in March of 1990. The mission of the centers is to *identify an individual's capacity to utilize technology based adaptive equipment required for successful performance in an educational, training, or employment setting, and to train the individual to a reasonable level of proficiency in the use of that equipment and related software in those settings.* This paper describes one of these centers in detail.

The University at Buffalo *Adaptive Technology Assessment and Training Center* (ATAT) is located within the Center for Therapeutic Applications of Technology. In addition to its service mission, this ATAT is developing a research program with a focus on the evaluation of electronic technology. The establishment of the Buffalo ATAT reflects a collaborative effort of a number of organizations: those working with the University at Buffalo faculty and staff include the Blind Association of Western New York, the Western New York Independent living Center, the Resource Center for Visually Impaired, and the Buffalo Hearing and Speech Center. The University's Center for Therapeutic Applications of Technology includes research, training and service components on applied technology in four major areas: (1) visual impairments, (2) cognitive impairments, (3) physical disabilities, and (4) seating and positioning systems.

Personnel for the Center include the Director of the Center for Therapeutic Applications of Technology, who provides overall management for the project, an evaluator / trainer (coordinator) who has several years experience in working with technology applications for persons who are legally blind, and an aid who assists with setup of equipment and materials.

The room for the *Adaptive Technology Assessment and Training Center* (ATAT) has approximately 300 square feet of floor space. The space accommodates a workstation for the evaluator / instructor, two training workstations, and additional bench space for assembling devices and storing equipment when not in use. The space was renovated to include additional electrical outlets, proper lighting, and security.

The ATAT Center provides services to Commission for the Blind and Visually Handicapped clients as an absolute priority. The number of clients receiving assessment and training services is limited only by the number of referrals and the capacity of the system, although CBVH has set the number of assessments at 16 for Year 1 and 20 for Year 2; 10 individuals will receive training in Year 1, and 14 in Year 2. The ATAT Center coordinator receives additional support from other professionals on campus, including rehabilitation engineers, therapists and rehabilitation counselors, who also derive information useful to related research activities. For example, client observations during the training process are used to improve the training approaches, and client feedback on the utility of a specific device leads to device enhancements. The ATAT Center is open from Monday through Friday from 8:30 am to 5:00 pm, excluding holidays.

The ATAT coordinator ensures that clients who are employed or are planning for a specific job, receive assessments and equipment recommendations that relate to the requirements of that particular job setting. The coordinator personally visits the job site, in cooperation with the referring CBVH counselor. Her visit provides the context in which to apply the CBVH counselor's report and the job–site evaluation.

Clients without a specific job target are screened for possible employment through two sources. One source is the Western New York Employers Task Force (ETF), two sources. One source is the Western New York Employers Task Force (ETF), which works closely with the Center for Therapeutic Applications of Technology in identifying positions for persons with disabilities who are using assistive devices. The fifteen ETF members represent large and small profit and non-profit organizations, and span the education, health, finance, professional and service industries. Another resource for employment is the Blind Association of Western New York's job placement program titled, *Job Development Services for the Blind and Visually Impaired.*

Training for each person takes from four to six weeks. Training includes experience on the latest available technology including the Navigator, the TSI Laptop System and software such as ZoomText. Training outcomes include the following; primarily related to IBM compatible systems:

- know the names and proper uses of all switches, buttons and controls;
- power-up and load the machine in the proper order without notes;
- navigate around the screen, locate and track the cursor, locate text/places without placemarkers, proof-read and edit;
- make all necessary adjustments to the adaptive equipment
- perform a minimal amount of trouble shooting on the equipment
- understand DOS and one or more of three application software packages (Word Perfect, D-Base III Plus, Lotus 123)

In addition to the assistive technology assessment and training activities, each ATAT Center coordinates housing for the training period, and transportation and mobility training to the Center. This project is sponsored by CBVH for a two year trial basis. Outcome evaluation will include numbers of persons successfully placed in jobs.

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Transport For The Disabled: The Hong Kong Approach

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Introduction

Transport for the disabled is essential in providing equal opportunities for the disabled within the society to undertake employment and other social activities. In Hong Kong, there is a particularly well established and heavily utilized public transport network, yet there exist many barriers to its use by the disabled. In 1977, a major review of provision for the disabled was undertaken by the Joint Council for the Physically and Mentally Disabled, and the 'Rehabus' service, utilizing minibuses to provide surface transport was proposed. With Government subsidy and private donations, the operation of 'Rehabus' was taken up by a local non-profit organization, the Hong Kong Society for Rehabilitation, and since then, the service has been steadily improved.

In order to ensure good service to the disabled, a committee was set up as the direct controlling unit of the Rehabus operation. In 1989, the Rehabus fleet comprises 37 twelve-seater minibuses operating on 30 scheduled routes and 2 full day 'dial-a-ride' service carrying over 300 passengers daily.

The Rehabus service

Rehabus offers a door-to-door service tailor made to the need of the passenger. The services currently provided are of two kinds; the scheduled route and the dial-a-ride. The schedule route service is designed to provide regular transport for the disabled to and from the place of work or study. The dial-a-ride service is a demand-responsive operation provided on an ad-hoc basis and at present, over 60% of the demand is from group users with half the utilization being for leisure, recreation and sports activities.

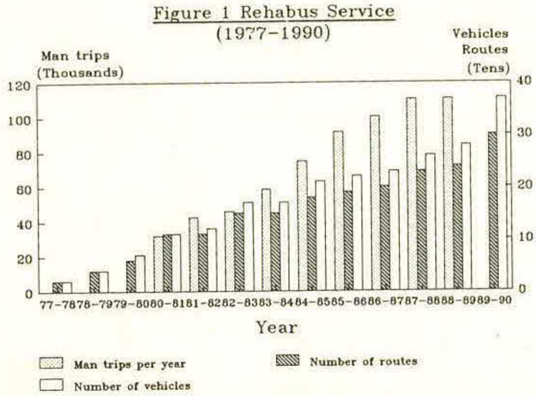
The Rehabus fare is set to correspond with the fare charges for other forms of public transport. At present the fare is $2.5 (US$0.3) per trip and $95 (US$11.9) per month for the scheduled route service, but for the dial-a-ride service, the charge will be calculated according to the traveling time, mileage and the number of passengers.

The fares raised represent over 20% of the operating cost of the service, which compares very favorably with any comparable system in the world.

Over the first 12 years, the demand for the service has steadily increased as a result of improved public awareness. However, of great concern are the findings of a recent telephone survey on the demand for Rehabus service, which indicate that among 403 disabled persons interviewed, 63% knew nothing about the service and only 11% of those who did know about the service knew how to make use of it. Even though, there has been a continual expansion of the Rehabus service as shown in figure 1, the demand has not been met fully. Currently, the waiting list is over 200, which suggest a need for at least 17 more buses.

In order that this limited service can be made available to those who have the most serious mobility problem, the committee has established a screening procedure for potential clients which takes account of the type of disability and the purpose of the trip. Table 1 shows the priorities categories.

Figure 1 Rehabus Service
(1977-1990)



Type of disability:

1. Wheelchair bound
2. Persons using crutches of calipers
3. Multiply handicapped
4. The mentally retarded:
   - (a) lower moderate and severe grades
   - (b) young females
   - (c) males, moderate grade
5. The blind-on a temporary basis

Purpose of trip:

1. Employment
2. Education or training
3. Medical treatment
4. Leisure,recreation and sports activities

Table 1 Screening Priorities of Rehabus

Future development

In 1989, under the aegis of the United Nations Development Country Project (UNIP), a independent study was conducted focusing on the future development of Rehabus services. Computerization of scheduling and routing was suggested. However, as the road network in Hong Kong is extremely complex and fast changing, due to construction work, computerize routing seems to be impractical. In terms of respond time to requests, the report has examined four different types of communication techniques in terms of cost and effectiveness, and the recommendation is to use mobile telephones.

As concerns technical aspects, a local standard has been formulated, which will be used as a guide line for bus selection. In terms of safety and comfort of passengers, seat arrangement and restraint systems were also included in the study. In order to increase the carrying capacity of Rehabus, the use of an exterior mounted tail-lift is recommended.

Conclusion

Transport service for the disabled will never be sufficient in any country unless public transport system are made accessible. The value of the Rehabus service cannot be denied and the service is set to expand and improve in a guided and structured fashion. However, in order for a disabled person to return to society with self-respect restored, barrier free mobility must be provided - greater access to buildings must be matched by improving access to transport. In view of that, the Rehabilitation Engineering Centre in Hong Kong has started working on projects and providing services in this area. These include the modification of a wheelchair for use on escalators, stair climbers for use under local conditions and adaptations to provide access to small private and hire vehicles.

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MUSICAL ACCESS STRATEGIES FOR THE COMMUNITY AND THE INSTITUTION: THEORY AND PRACTICE

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INTRODUCTION

The creative act of musical expression is one that is often out of the reach of persons with physical limitations. They may require some adaptation or other intervention in order to obtain musical experience. They may find a general lack of services, instructional programs, and funding to permit access. Additionally, they will have minimal opportunities for interaction and performance. Musicians generally have a clique which is difficult to break into, but the disabled performer has an additional hurdle in the form of classic attitudinal barriers.

For a person with musical experience, and a subsequent injury or disease resulting in disability, it can be like owning a map but not a car. You know where you want to go, but do not have the means to get there. It is especially difficult if you used to drive.

The Vancouver Adaptive Music Society was established to:

Provide an opportunity for creative musical expression to persons with severe disabilities by adapting and/or enhancing existing technologies;
Design music peripherals and software;
Develop assistive splinting devices to improve physical accessibility;
Create opportunities within the community for integrated public performances, group workshops, individualized training; and
Provide musical equipment (mainly high tech) to disabled individuals.

BACKGROUND

The primary impetus for this endeavor arose from the circumstances of the first author. From age 10 to 18, he enjoyed playing drums and piano in school as well as in a rock and roll "garage band". An accident at age 19 resulted in quadriplegia and the interruption of this enjoyment.

He wanted to resume that aspect of his life, and recognized that he would not be able to play in the same manner as before. The process he used to accomplish this goal is summarized below, to encourage physically disabled persons to take up creative expression, and to encourage the expansion of the skills of rehabilitation engineers into service in the creative arts.

METHOD

These steps are presented with musical expression as the example, but apply equally to the other creative arts.

1. Promoting musical expression
2. Identifying limitations
3. Experimenting individually
4. Identifying persistent limitations
5. Identifying and accessing resources to assist in minimizing persistent limitations and maximizing performance
6. Creating opportunities for performance

1. <u>Promoting musical expression</u>
This generally arises from within oneself, either by returning to an earlier skill and outlet(as in the case of the first author), or by desiring a new one. A means of creative expression should be encouraged as a part of normal living for physically challenged individuals. This can be facilitated by role models.

2. <u>Identifying limitations</u>
As he begins to express himself, specific physical limitations will be perceived by the individual himself. A lack of suitable equipment will become more apparent as his knowledge of available technology expands. Funding issues readily present themselves.

3. <u>Experimenting individually</u>
The basis for a solution starts by assessing oneself, knowing one's own capabilities and freely experimenting. The first author developed his own method of striking the drum by a supination/wrist extension movement. Another quadriplegic musician developed a technique for playing the keyboard without depending on the use of his fingers. He uses the heel of his hand to select keys.

4. <u>Identifying persistent limitations</u>
After experimentation, performance may still not measure up to desire or internal skill. Alone, or in cooperation with rehabilitation personnel, the limiting factors can be isolated.

The first author found that firmly holding his drum sticks was not achievable by any method he tried. Additionally, after he

acquired an electronic, programmable drum pad, he was unable to operate an essential edit function switch as it was out of his reach at the back of the unit.
The second musician found that he could play one or two piano keys at a time, but was not satisfied with this level of "music".

5. Identifying and accessing resources to assist in minimizing persistent limitations and maximizing performance
At this point, the individual requires assistance. Phoning the various agencies dealing with the disabled population will yield leads for follow-up. The individual should not afraid to ask for technical assistance from any source, including manufacturers of electronic musical equipment and university engineering departments.
The first author worked with the second author to develop an alternative method of independently and firmly holding drum sticks. The solution consists of an adapted push grip fitted with strapping mechanisms and velcro stability pads fabricated with a flexible yet durable construction to allow for a firm, responsive stroke.
Engineering students at a local university were challenged with the switch control problems as part of a design course. Working with the first author, they developed a pad switch, easily located within reach which could be used to trigger the edit function.
Another group of students developed software to allow the second musician to program more than one note, or instrument type, to any individual key on his electronic MIDI (Musical Instrument Digital Interface) keyboard.
A major manufacturer of musical equipment was approached and readily assisted with specifying equipment and detailed technical information.

6. Creating opportunities for performance
Jam sessions and practices occur spontaneously when a group of musicians becomes acquainted. A local residential institution sponsored a band, thereby minimizing travel constraints. The chance to perform for a wider audience may require more effort, but has occurred naturally as well, often due to the contacts developed in progressing to this level.
The contact with the manufacturer and the regular schedule of trade shows led to an invitation for the performance band to open for UZEB. Contact within the disabled community in planning other events has also generated opportunities, such as playing at annual meetings or as part of a "arts by the disabled" program. The local science center was intrigued by the "new" use for technology and requested a special performance. These events were covered by local and national television and newspapers, which generated additional bookings.

ADDITIONAL DEVELOPMENTS

A local university engineering department and other individuals have been working on additional projects which include: stringless guitars, sip and puff MIDI sound controllers, head switch keyboards, and a "jamming" modem. We hope to see the details of these devices presented at this and future conferences.

CONCLUSIONS

The need for a creative outlet is often overlooked by a traditional rehabilitation engineers and viewed as impossible by persons with disabilities. The psychological benefits of creativity are well recognized: a feeling of self-worth and accomplishment, a unique sense in creating that expands one's personal depths. Add to this the restoration of abilities previously considered lost and it adds up to a powerful combination for the disabled individual.
We hope that we have challenged rehabilitation engineers and disabled individuals to become involved in this process.

ACKNOWLEDGEMENTS

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Jeff Koftinoff for technical and creative inspiration and lots of leg work.
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INDIANA'S RURAL REHABILITATION TECHNOLOGY NEEDS

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INTRODUCTION

In September of 1988, the Breaking New Ground Outreach Program was initiated. The Outreach Program is a joint service of the Indiana Easter Seal Society and the Breaking New Ground (BNG) Resource Center. The Program is an outgrowth of the BNG Resource Center which was established in 1979 to provide services to farmers with physical disabilities.

Services of the Outreach Program involve: 1) access to resource material available from the Breaking New Ground Resource Center including a newsletter, technical articles, resource manuals and video tapes; 2) On-site farm visits for assessment and information sharing purposes; 3) Participation in support group meetings and workshops; and 4) Public awareness activities.

The staff of the Program consists of a full-time program coordinator who is a C.O.T.A.; part-time clerical support and both paid and volunteer student assistance.

NECESSITY OF THE PROGRAM

Agricultural production is ranked as the most hazardous occupation in the United States, with the highest disabling injury rate of any industry. An Indiana farm accident study, released in November of 1988, has shown that one in nine farm families in the state are affected by a farm accident each year. Based upon 72,000 Indiana farms, this means over 8,000 farm-related injuries occur each year with approximately 60% requiring emergency medical treatment. An estimated two percent of those injuries result in some form of permanent disability.

In 1987, the Indiana State Board of Health, Division of Handicapped Services estimated that there were 5,499 spinal cord injured Indiana residents. If randomly distributed, the data suggests that approximately 250 individuals with spinal cord injuries live and work on Indiana farms. During the first 15 months of the Program, over 30 have been identified.

Clearly, the potential exists to provide expanded rehabilitative services to the residents of Indiana. Residents living in rural areas are of particular concern because of their isolation, the distance some travel for quality health care and the lack of knowledge about available resources and services.

CLIENTELE

Tables 1 and 2 provide information on the age distribution of clients and the types of disabilities served through the Breaking New Ground Outreach Program from September of 1988 to December of 1989. With a few exceptions, the client population is mainly comprised of physically disabled farm family members.

Table 1: Age Distribution of Clients

Age Category	Number Served
0-2	1
3-15	5
16-21	6
22-64	93
65-up	19
Unknown	29
Total Clients Served	153

Table 2: Types of Disabilities Served

Type of Disability*	Number
Paraplegic	24
Amputee	
Upper extremity	12
Lower extremity	13
Arthritis	13
Back injury/difficulties	7
CVA/stroke	7
Crush injuries	6
Hand injury	6
Quadriplegic	5
Respiratory condition	4
Visual impairment	4
Cardiovascular difficulties	3
Cancer	3
Multiple sclerosis	3
Polio	3
Head Injury	2
Laryngectomy	2
Obesity	2

* Client may have more than one type of disability

Individuals with a variety of other disabilities were also seen including ALS (amyotrophic lateral sclerosis/Lou Gehrig's disease), Alzheimer's disease, anemia, aphasia, burns, carpal tunnel syndrome, determatomyositis, diabetes, Ehlers-Danlos syndrome, Guillain-Barré syndrome, hearing impairment, kidney transplant, knee injury and spinocerebellar ataxia.

SERVICE DELIVERY ACTIVITY

Table 3 summarizes information on service delivery activities since the start of the Breaking New Ground Outreach Program.

Table 3: Service Delivery Activities

Services (More than one service may have been provided per individual.)	**Approximate Client Total**
Information (to solve specific problems, obtain printed material)	145
Farm visits (for assessment and information sharing purposes)	68
Referred to another service provider (i.e. Office of Vocational Rehabilitation, another health care professional)	43
Follow-up to a referral that we received	34
Support group attendees	34
Support persons or requests (to speak with another disabled individual)	21

Public awareness has been an extremely important component of the Outreach Program. Staff have been involved with over 33 speaking engagements, field days, workshops, farm shows and other public events. One recent exhibit had the potential of reaching approximately 20,000 farm families with information on available rehabilitation services. In addition, the Program has used the rural media to carry stories on case histories. Resources and information have also been provided to County Extension Agents, 4-H volunteers, Vocational Agriculture instructors, and local farm organization leaders.

CLIENT NEEDS

Based upon service delivery activities and observation, the rural rehabilitation needs of Indiana residents, served through the Outreach Program, can be summarized as follows:

Rehabilitation information
Rehabilitation information is one of the primary needs that is articulated by the clients served. This has become evident by telephone contacts, written correspondence, and on-site visits. Information, for example, is desired on how to modify machinery, tools and buildings, to make them accessible and operable; safety considerations are also of concern. A need exists for awareness and availability of adaptive aids currently on the market. Assistance in interpreting information and outlining viable options consumes considerable amounts of time as well.

Referrals
In many cases clients are in need of services not provided by the Program or that could be provided by other agencies or resources more effectively. People are referred to other service providers such as the Office of Vocational Rehabilitation, rehabilitation hospitals, or mental health agencies if the Outreach Program can not appropriately meet an individual's needs.

Support
Giving and receiving support is another area of need. Three support group meetings have been held at various locations since the start of the Program. Individuals gather to share experiences and ideas for coping with their disability. Individuals are also willing to be support persons for more recently disabled farm family members. Although attendance at support group meetings has been low, the need for individuals to be available as peer support persons is significant. Recently disabled farm family members seem eager to speak with others in a similar situation; not only for the purpose of sharing experiences, but also for obtaining information on specific aids (i.e. wheelchairs suitable for rough terrain or selection of a specific type of prosthetic device) and service agencies or providers.

COST OF SERVICES

Comprehensive cost data is not available for the Outreach Program since it is being conducted on trial basis by two larger organizations which have absorbed some of the costs such as administration, office space and utilities. Table 4, however, summarizes the actual out-of-pocket expenses for the first year which provides a good estimate of what it would cost to duplicate the Program elsewhere under similar circumstances.

Table 4: Summary of Annual Program Costs

Salaries and fringe benefits	$ 26,500
Travel, subsistence, and lodging	2,250
Communications and printing	3,200
Supplies and equipment	1,300
Overhead and administrative services	3,500
Other	250
TOTAL	$ 37,000

ADDITIONAL INFORMATION

For additional information about the Breaking New Ground Outreach Program; please contact:

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A Vocational Assessment Model for Use of Robotics Technology

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ABSTRACT

A vocational assessment model was developed by the clinical robotic staff at the Palo Alto VA in order to determine appropriate placements of a vocational robotic workstation with disabled employees. This model was based on comprehensive evaluations of over 30 individuals with high-level quadriplegia, and their family, attendants, co-workers and employers in the clinic, home and work settings. Based on the use of this model, four individuals were assessed for trail placement of the robotic system; two were chosen. The system is now being consistently used on a daily basis to perform daily living and vocational activities for a quadriplegic systems analyst programmer at Pacific Gas & Electric.

INTRODUCTION

The use of robotics technology as an assistive tool for disabled individuals is beginning to move out of the research labs and into clinical, educational, and vocational settings. These workstations have the capability to provide independence in performing daily living and work-related activities for severely physically disabled individuals who are otherwise dependent on the assistance of a full-time attendant. Due to the high cost of this technology, its limited availability, and the amount of personnel and time involved to install a system, an assessment model to determine appropriate users and worksites is needed in order to justify implementation of such a system.

This evaluation must examine the disabled user and his/her needs, the prospective employer and co-workers, and the worksite environment in order to ensure successful placement. Four of these vocational evaluations have been conducted at the Palo Alto VA SCI Center in order to determine appropriate trial placement of the desktop vocational assistant robot, DeVAR, in the workplace.

BACKGROUND

This vocational evaluation model is based on research and development of the DeVAR system which has taken place over the past 10 years. Over 30 quadriplegics have participating in clinical evaluations of the DeVAR system which focused on performing daily living activities [1]. Based on feedback from disabled users and corporate employers, a workstation which could provide both vocational and daily living assistance in order to return quadriplegics to productive employment was developed. In order to design the system and determine which tasks needed to be added, four comprehensive evaluations of quadriplegics who were working in computer-related jobs were performed by the team occupational therapist.

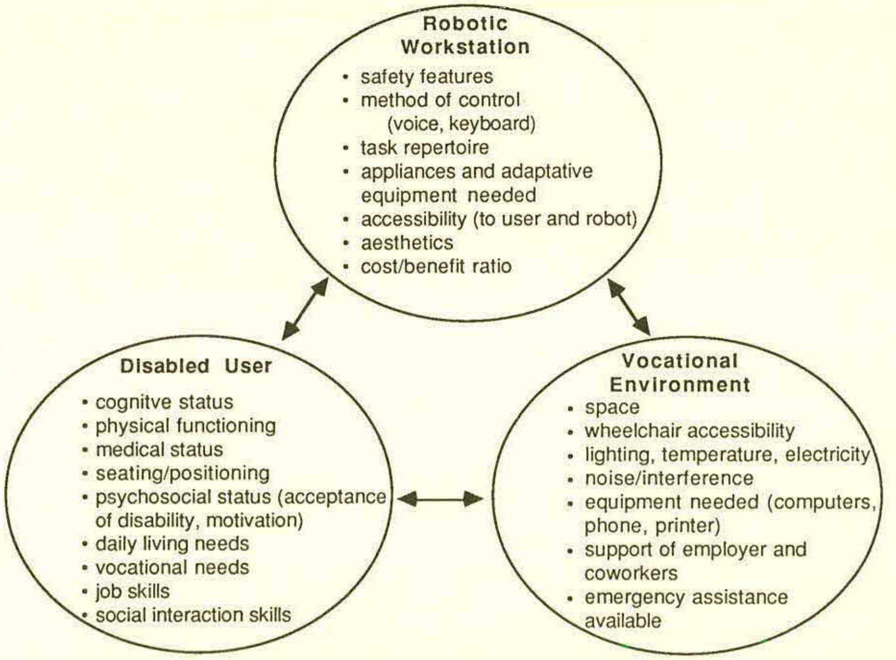

Figure 1. Assessment Model for implementation of a vocational robotic workstation.

Of the four individuals who were evaluated, two were chosen for extended trial evaluation sites: one at a school for disabled programmers and a second at Pacific Gas & Electric (PG&E) Company. The current system is being used on a daily basis at PG&E by a C3 level quadriplegic who is a systems analyst programmer. The DeVAR system uses an industrial robotic arm, the PUMA-260, mounted over a work table on a four foot track to perform daily living and vocational tasks via voice and/or keyboard commands from the disabled employee.

METHODS

Initial evaluations of the disabled individuals were conducted at the Palo Alto VA SCI Center by the occupational therapist (OTR) and were then followed by extended visits to the homes and worksites. Evaluations focused on three main areas: the disabled user, the robotic workstation, and the vocational environment (see Figure 1).

Disabled User:
Functional status was measured in terms of the disabled individual's cognitive status (reaction time, judgement, attention span), physical function (range of motion, strength, sensation, endurance, identification of most reliable anatomic activation site for controlling the robot and computer), medical status (vision, hearing, respiratory status, skin integrity, medications), seating/positioning, daily living needs, vocational needs, and psychosocial status (acceptance of disability, motivation). This information was gathered from evaluations performed by the OTR, medical charts, multidisciplinary team meetings, and separate interviews with the disabled person, family, and attendants.

Vocational Environment:
Two days were spent observing the individual in his home and work environment. Recordings were kept of the daily living and vocational tasks performed as well as the type and amount of assistance needed from the attendant per hour. Attendants were also asked to record this information over the period of a week. Interviews with the employee's supervisors and corporate executives were also conducted to determine the employee's needs and level of support from the employer and co-workers in terms of accommodating these needs. A composite graph of a "typical" work day was generated from this data. Additionally, the worksite was evaluated to determine space requirements, lighting, temperature, accessibility, level of noise interference, and equipment required (computer, phone, printer).

Robotic Workstation:
Based on the above evaluations, the robot team worked together to adapt the robot workstation to fit the individual needs of the disabled employee. Of paramount importance was the incorporation of safety features including the ability to stop the robot by voice, by loud noise, and by emergency stop switch at any time. Other features which were evaluated and adapted included: the control method for using the robot (voice, keyboard), the task repertoire, aesthetics of the system in terms of blending into the corporate office setting, and accessibility to both the disabled user as well as the robot arm in handling supplies and equipment.

RESULTS

Four comprehensive evaluations of disabled employees were conducted. It was found that an evaluation of the disabled user, the worksite, and the robotic workstation equipment by a team of evaluators including an occupational therapist familiar with the technology and a robot engineer was required in order to ensure successful implementation. Based on the results, the existing DeVAR system was adapted and refined and then placed into two worksites for extended trial evaluations. The second placement has proven the feasibility of using the robot to replace a human attendant for an entire workday in a desktop job such as computer programming.

DISCUSSION

Through the evaluations and placements of the system, it was determined the optimal placements of a robotic workstation would be in occupations which are desktop-oriented and which emphasize the creative, cognitive abilities of the disabled employee as measures of productivity, rather than speed and manipulation abilities. Sample jobs may include computer programming, database management, technical support, accounting, administration, desktop publishing and presentation, and computer aided design and drafting. Additionally, the motivation of the disabled employee and level of support from the employer, supervisors, and co-workers were found to be important factors in determining the success of placement of any assistive technology, especially in regard to a sophisticated robotic workstation.

CONCLUSIONS

With the proven feasibility and reliability of robotics technology, workstations which can provide independence and a means for securing productive employment are becoming increasingly desired by and available to severely disabled individuals and their corporate employers. In order to ensure this technology is used optimally, comprehensive vocational assessments should be implemented before prescribing a system.

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RTX Robot Control Library: Straight Line Motion

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ABSTRACT

Software based trajectory control, in real-time, of a robotic manipulator along a straight line is the focus of this work. A function which provides straight line motion of a robotic manipulator is a necessary part of a rehabilitation robotics library. Control of a robotic manipulator along a straight path is possible using various control schemes. Four control schemes have been implemented to a computer graphics simulation of the RTX robot. Problems and sources of error have been exposed. Potential solutions are stated.

BACKGROUND

The Rehabilitation Robotics Programming Environment (RRPE) [1] provides a development tool for use by programmers and researchers in developing an interface between the human user and the robot. The RRPE is designed to be modular, and easily portable to different robot systems. A major component of the RRPE is the Robot Control Library (RCL). This standardized library provides the programmer with functions and procedures for robot control. The first RCL to be developed is for the RTX from Universal Machine Intelligence [2].

In a rehabilitative environment, the robotic manipulator is intended to augment or replace the functionality of a user with disabilities. Therefore, it is vital that the manipulator closely replicate human motion. Human motion includes the ability to move our hand to a specific location in space or trace our finger along a path. This type of hand-oriented control is called *trajectory control*. The RCL must therefore provide *trajectory control* over the robot. Trajectory control over a robot means the ability to control the path and orientation of its end effector.

A major difference between human motion and robot motion is that we can move our hand along a path without conscience calculation of the position or speed of our various joints, whereas the joint angles and speeds of a robotic manipulator must each be explicitly computed. A primary goal of the RCL is to reduce the prohibitive mental overhead associated with robot control.

Of trajectory control, straight line motion is a fundamental subset often employed by humans. Therefore, a major component of the RCL is a set of functions which provides straight line trajectory control. This paper specifically addresses the implementation of straight line trajectory control on the RTX.

BASIC ROBOT CONTROL[3]

In order for a robot to achieve a specified point or trace a prescribed path with its end effector, the angles and velocities at each joint must be explicitly and continuously calculated. The position of the end effector in space can be uniquely described by a set of six *coordinates*: three *cartesian* coordinates, and an orientation described by a *roll-pitch-yaw* system. Given the joint angles and the specific robot geometry, the position and orientation of the end effector can be calculated. This is called the *kinematic solution*. It is also possible to calculate the joint angles required to achieve a specified position/orientation. This operation is the inverse of the kinematic solution, and is thus called the *inverse kinematic solution*.

Specifying the end point of a move, calculating the joint angles necessary to achieve this point, and moving each joint to the correct location does not, however, guarantee the desired straight line motion. To do this, the velocity of each joint must be controlled. Therefore, it is necessary to relate the cartesian velocity components of motion to the velocity of each joint. Just as the kinematic solution relates joint angles to end effector position, the *Jacobian* (**J**) is a matrix which relates joint speed to the cartesian velocity of the end effector. The *inverse Jacobian* ($\mathbf{J}^{-1}$) relates the end effector velocity to joint speeds and is the matrix inverse of the Jacobian.[1] Unlike the kinematic solution which is a constant function, however, the Jacobian, and therefore its inverse, is a function of position (joint angles, θ), such that $\mathbf{J}^{-1}(\theta)$ needs to be calculated at every different position of the robot (i.e. calculated continuously). $\mathbf{J}^{-1}(\theta)$ is then used to calculate the necessary joint speeds, $\dot{\theta}$, to achieve the desired cartesian velocity at the end effector. Equations 1 and 2 show the relationship.

$$v = \mathbf{J}(\theta) \cdot \dot{\theta} \quad (1)$$

$$\dot{\theta} = \mathbf{J}^{-1}(\theta) \cdot v \quad (2)$$

where v is the *cartesian* velocity vector and $\dot{\theta}$ is the *joint* velocity vector.

Using the inverse Jacobian, real-time, straight line motion is possible. Various *control schemes* which achieve real-time straight line motion and minimize error is the continuing focus of this work. Error is defined as a deviation from the straight path between two points, or a deviation in the desired velocity.

1. Both the kinematic and Jacobian solutions depend on the geometry of a specific robot and are, therefore, robot specific.

CONTROL SCHEMES

Four distinct control schemes have been implemented on a computer graphics simulation of the RTX joints. The basic components of all the control schemes are:

- calculation of a velocity vector between two positions
- calculation of the needed joint velocities to achieve the desired velocity
- updating the robot joint velocities.

Control Scheme 1 calculates the cartesian velocity vector, v, between the initial and target positions, once, and computes the necessary joint velocities ($\dot{\theta}$) which provides v, instantaneously, for the specific joint positions (θ), and sends these joint velocities to the robot or graphics simulation. When the robot begins to move, the joint angles, θ, change. Since $\mathbf{J}^{-1}(\theta)$ depends on θ, $\mathbf{J}^{-1}(\theta)$ needs to be recalculated. Using the new $\mathbf{J}^{-1}(\theta)$, new joint speeds are calculated, using equation 2, which provide the desired cartesian velocity at the end effector. Since the original velocity vector is used throughout the move, error is never compensated.

Control Scheme 2 recomputes the vector v from the current end effector position to the desired target every time $\mathbf{J}^{-1}(\theta)$ is recalculated. By doing this the end effector is "gravitated" to the target position.

Control Scheme 3 incorporates a simple error correction feature. Two cartesian velocity vectors are computed: one between the current position and the target position, and one between the current position and a point back to the path line if there is any error. The two vectors are added to provide a vector which will not only "gravitate" the end effector towards the target but back to the desired path. Like control scheme 2, the new vector is continuously updated throughout the move. This added complexity increases the computation time interval.

Control Scheme 4 continually calculates a velocity vector between the current position and the position on the line which the end effector should achieve in some small time interval. The joint speeds which provide this motion must be sent at precise intervals to provide the control in real-time.

As each control scheme becomes increasingly sophisticated the time interval needed for calculation increases as well. An increased time interval increases error. Therefore, a trade-off exists and no one scheme can be predicted to be better than the other for all possible applications. Only though testing the performance of each scheme over various paths can this be determined. This is the focus of future work.

PROBLEMS AND SOURCES OF ERROR

Since $\mathbf{J}^{-1}(\theta)$ is a function of position, it needs to be calculated for every position the robot takes throughout the move, that is, calculated continuously. Since the execution of the algorithm loop takes a discrete amount of time, continuous calculation of $\mathbf{J}^{-1}(\theta)$ is impossible, and must be calculated at discrete intervals. The calculation of this matrix is not a trivial matter and can take a significant amount of time. The time needed to communicate with the robot is also appreciable. Every robot joint must be read from the robot, the kinematics performed, the velocity vector calculated, the inverse Jacobian computed, the new joint speeds calculated from $\mathbf{J}^{-1}(\theta)$, and then the robot updated with these new speeds. Given this massive computational and communication overhead, the time interval becomes a significant source of error. Presently, the time interval varies from 0.17 seconds for Control Scheme 1 to 0.25 seconds for Control Scheme 4. These times were obtained using an Intel 80386 processor running at 20MHz, equipped with a 80387 math co-processor, running under DOS v3.3.

Other, robot specific, sources of error have been identified:

- communication lag - by the time the calculations are made and the new velocities are ready for the robot, the arm moved to yet a new location.
- quantization error - the RTX truncates numerical values to integers, therefore there is a loss of accuracy.
- acceleration error - since a robot is a physical, dynamic system, there is an acceleration time associated with changing the speeds of joints.

SOLUTIONS

Various approaches implemented to the control schemes for improved performance are listed:

- positioning forecasting - making calculations based on where the joints will be at the time of communication
- improved model - developing a better dynamic model of how the robot actually behaves to various commands.
- interval reduction - streamlining the code to reduce the time interval as much as possible

ACKNOWLEDGEMENTS

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CAPITILIZING ON ROBOT TECHNOLOGY - MAD, MOM, DAD AND NEXT

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ABSTRACT

After ten years of managing industrial robotic design and development, a personal assistant robot project appeared very straight forward. Seven years and eight hundred thousand dollars later, we are now ready to test the waters. Taking well established, and well understood technology, and applying it to the field of personal assistance for people with severe physical disabilities involves stepping into the world of long term care and of rehabilitation. Most importantly, it means stepping into the realm of people with disabilities who are stripped of self control over their environment and are maintained in a caring environment devoid of funding for liberation. This step by step story chronicles technology transfer in a complex multifaceted field with the consumer in "consumer acceptance" difficult to define.

Modern robotic mechanical technology is now forty years old. It was just a few years after World War II that nuclear researchers working with teleoperator hazardous environmental manipulation established that the minimum number of reversible motions required to reposition and reorient objects in space were six. This is the well-known six degrees of freedom. Just five years later, U.S. airforce sponsored studies in digital control led to the next major breakthrough for robotics. This was capitalized on by Engleberger productizing Devol's patented ideas for factory robots with the founding of Unimation, Inc.

In 1983, in the hazardous environment robot development group of a leading Nuclear Research Facility, we had a low priority requirement for a man sized programmable arm and gripper to so some miscellaneous tasks in a low level radioactive environment. To maximize the investment we decided to devote the energy and cost into developing a manipulative machine that could be programmed with several databases and used in long term care centres to assist residents with severe physical disabilities with physical tasks that they could not themselves perform.

All available literature on so-called "rehabilitation" robots was reviewed, and site visits were made to all known operating assistive robotic research programs in Europe, Japan, the U.S.A. and Canada. In the summer of 1983, specifications were established after consultation with leading robotic researchers, rehabilitation professionals and most importantly, with a large number of individuals with severe disabilities. Focus groups were first shown videotapes of industrial robots and current programming techniques. A large wishlist was established and task/envelope analyzed to establish the most viable coordinate system and envelope size. Mobility was eliminated for computer cost/size limitations. Position sensing,orientation algorithms and smart systems in 1983 were too expensive and bulky. Simplicity, minimum mass, reliability and low cost were overriding considerations.

The resulting configuration ended up pretty much as an attendant sitting down and facing the user. Reaching to the floor was eliminated as not worth the extra size and cost. An articulated arm (elbow) was deferred in the hope that a simple sliding arm could be made to work without precision tolerances (it did). Space was provided for optical encoders but potentiometers were used in the belief that they would provide acceptable results (they did). A fully adjustable low level PID control system was developed based on a low cost processor (6809) and it is still more than adequate. Eight bit feedback and control calculations were used but later these had to be updated to ten bit to achieve the desired accuracy. Supervisory control would be from any PC computer via RS 232. Even a Sinclair would be used, although all our development was based on IBM PC (compatible). A 24 volt dc servo system was incorporated and expensive but reliable motors/reducers were specified. Keyboard programming and hand-lead through teaching (actually taking it by the hand and leading it through) were utilized. Shaving with an electric razor was selected as an essential task. Desired programs were called up by the disabled user using single or dual switch input, or by voice. The robot was referred to as a Manipulative Appliance with Database, or "MAD". Two prototypes were built and a fifteen month clinical testing program was established in 1987-1988 at a long term 180 bed care centre for young adults. By this time, technology and funding was transferred to a non-profit rehabilitation group.

The clinical testing was conducted with fourteen residents, most of whom were literate, and a couple were visually limited. All were severely physically impaired. The major surprise for the researchers was the realization that virtually all users, regardless of literacy level, computer knowledge or severity of disability, wanted full control of the robot at all times. They wanted the power to program, to stop, back up, modify, correct, reprogram - to be in control.

This realization required a major expansion of our supervisory control software development program. A variety of user inputs were provided for, including scanning. A full window menu system was developed. The user now has full control of every motion at any time. This includes control over the value of the PID controller parameters. The safety system was expanded to include microprocessor redundancy, and sensing of any aberration in signal generation or feedback, or expected drive torques. The geometry and mechanical construction remained basically the same but all drives were refined. The robot was now a Manipulative Obedient Machine, or "MOM."

The time has come to capitalize on this robot technology. Industrial applications that could use the extremely user-friendly programming were looked into. Such applications could reduce the cost through increased production. A third prototype was sold to a company to handle pharmaceuticals in production. They purchased two more. A fourth unit was sold to another pharmaceutical manufacturer to work in a hot cell. A few thousand hours of regular operation were accumulated. A few electrical and mechanical weaknesses were corrected. The ten bit processing was completed and retrofitted. We felt confident we were ready to capitalize on this robot technology. The product was transferred to a commercial company for manufacturing and marketing.

The North American markets are targeted first for direct sales and servicing. The electrical certification requirements have been met. The social and economic mores in the rehabilitation system in the U.S.A. and Canada led us to first market the product as a work station robot to be used in the workplace as a simple manipulative device. The robot will perform simple little tasks such as moving paper or files, picking up a manual and turning pages - the kinds of tasks that, if not performed, can bring a computer literate worker with severe physical disabilities to a complete standstill. The name "MOM" had to go in this employment equity environment! The product is now a Robot Work Station Attendant or a Device for Assisting Disabled ("DAD"). The People's Republic of China has also obtained a license to produce and distribute this robot in their country.

The first three "shake down" production units have been delivered. The first installation was made in the playroom of a school for children with severe disabilities in Montreal, a market we have never considered. To date, we have made and sold eight units. A marketing program aimed at the three levels of user, recommender and funder (the three R's) is being launched in the Winter of 1989-90. As this application for robotics is new, the primary marketing mode will be demonstrations and workshops. The industrial market is being handled separately and that marketing is primarily through trade shows and sales representatives.

We in the development team feel strongly that every unit sold for use by people with severe disabilities must be closely monitored and serviced. We have pledged that all the profits to go into such service. It is most important to all of us in this rehab/technology business, and to all those with severe physical limitations, to find out exactly how manipulative technology will really be used, and how it can really be of benefit to potential users.

Researchers in robotics cannot possibly know how, in our discriminatory society, people with disabilities will really want to use robotic technology. No one in the robot business knows, or can know, without extensive consumer utilization. Marketing plans are to deliver fifty units for serious use, and then we will all begin to learn what is really needed. The original design team is ready to go on our next robot design. Some new principles are already being explored. Perhaps an arm on a chair that can reach the floor and still fold up totally out of the way. Possibly the chair can travel independently with no one board so that when the owner is down with a cold for a few days they can send the arm to the kitchen to fetch a drink, or the den to pick up a book. We are ready, but we don't dare start - not until fifty users have tried to destroy our first fifty installations!

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RTX Gripper/Motor Studies

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ABSTRACT

On the RTX robot, made by UMI, an effort was made to adequately control its two tonged gripper as a function of force and/or position on its controlling motor. The gripper provided with the RTX was used with the hope that its functionality would be adequate, thereby saving time and money by avoiding the purchase of an appropriate end-effector. To properly understand the material presented in this report, one should have a working knowledge of the RTX and be familiar with its documentation. The motor response was studied in two modes: *Force*, and *Position*. For each mode, the behavior of the parameters *current force* and *motor position* were recorded during the time the motor was told to move. This paper presents a report of these efforts and conclusions drawn from the various studies conducted.

TESTING METHODS

All the tests presented here were conducted as the gripper opening its fingers (this is the positive direction for the gripper motor) from a relaxed, closed grip to its outer endstop. The range of motion was from 136 to approximately 1300 encoder counts. Manual motion was used in *force* and *position* mode. In each case, the default values for the RTX control parameters were used except where noted. For each trial the *error* buffer (ERR), the *current position* buffer (CPOS) and the *current force* buffer (CFOR) were read as fast as possible while the robot was moving. CPOS and ERR are measured in encoder counts. The measurement for CFOR and the *maximum force* buffer, MAX FOR, is a number from 0 to 64[1].

FORCE MODE AND CURRENT FORCE

Figure 1 shows the graph of CFOR vs. Time for various values of MAX FOR using Force-Manual Motion. The sharp decrease and plateau in each trial represents the gripper reaching its outer endstop (see Figure 2). The value at each trial's plateau is the value set for MAX FOR. When the motor is not moving but is being told to move, CFOR=MAX FOR. Note that the trial for MAX FOR=5 produce dramatically different results. CFOR never goes above its MAX FOR for the duration of the trial. Figure 2 shows that this trial does not produce much motion. We conclude that this behavior is due to the effects of stiction (static friction) on the motor. Each axis on the RTX has a different amount of stiction based on load, gearing, etc. For the gripper motor, a MAX FOR value greater than or equal to 6 is required to overcome the stiction in the motor.

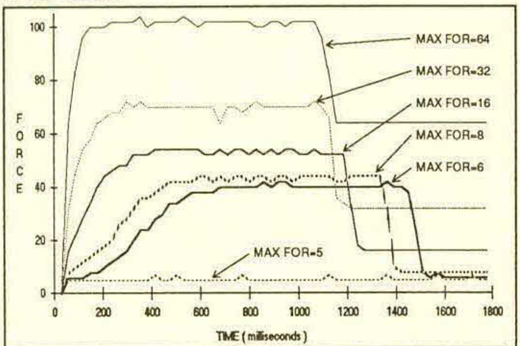

FIGURE 1: FORCE vs. TIME Using Force-Manual Motion

In Figure 1, note that the maximum attained force for each trial significantly exceeds the MAX FOR value set for that trial (e.g. for the MAX FOR=64 trial, the maximum attained force was 104). Clearly, this is impossible (see footnote 1). We have concluded that the value returned for CFOR is an error. Apparently CFOR was calculated by adding an increment proportional to motor speed. This should have been subtracted instead. This implies that the RTX is using an incorrect formula to calculate CFOR, however, this should be verified in the microcode of the RTX.

FORCE MODE - POSITION ANALYSIS

Figure 2 shows the graph of Position vs. Time in Force mode at the same values of MAX FOR used in Figure 1. Normally, *actual position* is calculated

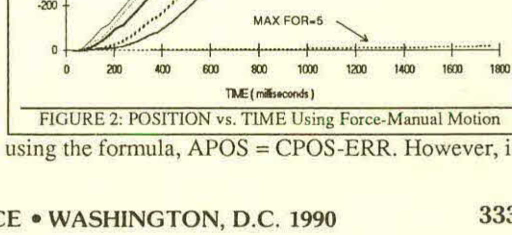

FIGURE 2: POSITION vs. TIME Using Force-Manual Motion

using the formula, APOS = CPOS-ERR. However, in

1. The voltage applied to the RTX is pulse width modulated. A value of 1 represents a minimum pulse width and a value of 64 represents constant voltage. 0 represents no voltage

Force mode, CPOS does not change so essentially APOS = ERR. The plateau at the top of the graph is the gripper reaching its endstop.

When Figure 2 is compared with Figure 1, it is clear that the MAX FOR=64 and MAX FOR=32 trials have almost the same position response. This means that once the motor overcomes its stiction, it responds virtually the same for any MAX FOR equal to or above its "stiction value."

POSITION MODE - CURRENT FORCE

Figure 3 shows the graph of CFOR vs. Time using Position-Manual motion for various MAX FORs. The sharp increase in the 64 and 32 trials is the gripper reaching its endstop. This graph shows that, while moving in position mode, the servo loop never requires CFOR to be greater than 24 to provide the demand response. MAX FORs set below this value will constrain CFOR to MAX FOR, instead of at the endstop as in the MAX FOR=64 and 32 trials. At the endstop, CFOR cannot be maintained for very long before the gripper motor "resets" and turns itself off[2]. For the MAX FOR=13 trial, this happens before the gripper reaches its endstop, and since a smaller CFOR results in slower movement, ERR grows quicker.

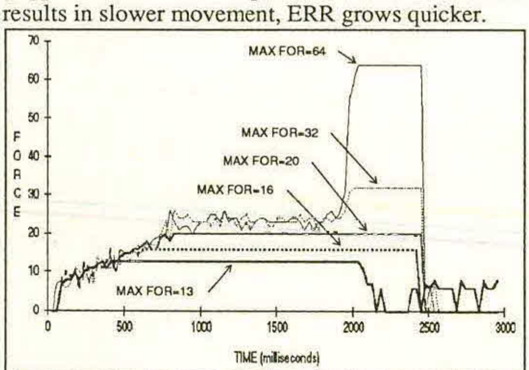

FIGURE 3: FORCE vs. TIME Using Position-Manual Motion

POSITION MODE - POSITION

Figure 4 shows the Position vs. Time graph using Position-Manual motion with various MAX FORs. For these trials, APOS = CPOS-ERR. The plateau at 1300 encoder counts is the endstop for the gripper motor. The MAX FOR trials above 20 are not included because they all showed the same response as the MAX FOR=20 trial[3].

2. In Position mode, a motor will reset when ERR > 2×Error Limit.

3. The spikes in Figure 4 result when a motor resets. The RTX must clear ERR and add ERR to CPOS. Unfortunately, both registers are not changed simultaneously and can be read "while in transition." Since the ERR register changes first and APOS = CPOS-ERR, incorrect values of APOS can be calculated with potentially disastrous results.

The trials, where MAX FOR < 14, never reach the endstop plateau. As a matter of fact, the servo actually reverses the motor direction in order to return to the place where it reset.

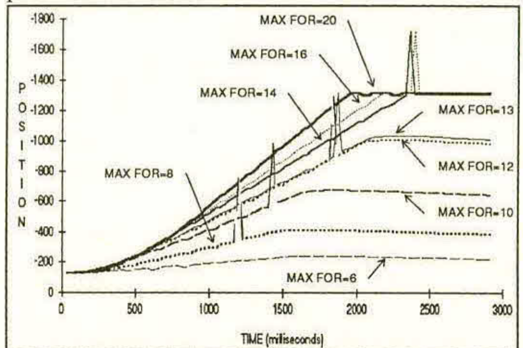

FIGURE 4: POSITION vs. TIME Using Position-Manual Motion

CONCLUSION

In the end, combined Position/Force control at the gripper is difficult to realize. In Force mode, we can control the force on the motor but don't have accurate control over its position[4]. In Position mode, we have control over the position, but lack adequate control over the force on the motor. We cannot switch randomly between modes for there are inherent problems with it which are beyond the scope of this paper. In order to achieve any reasonable Position/ Force control on the gripper, ultra-sonic and force sensors at the fingertips of the gripper may be needed

ACKNOWLEDGEMENTS

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4. It should also be pointed out that the force on the motor and the force at the fingertips of the gripper can be very different.

The PCF8200 Formant Speech Synthesizer: A Primer

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Abstract

Although formant coding of speech for synthesis is a common technique, a single chip device, the PCF8200 is proving to be an effective and economical tool. The device allows the user control of up to five individual formant filters, source type, pitch and frame duration. In addition, formant quantization tables are stored on-chip for both male and female speech characteristics. This paper is an introduction to the PCF8200 from Philips Components, and a look at potential applications as a universal synthesis device.

Introduction

In the area of augmentative communication aids and learning tools, text to speech is the most common use for synthetic speech. The process of converting text to speech can be split into two processes, analysis and synthesis (1).

The analysis portion may take many forms. The goals of the analysis section include formulating syntactic structure of the sentence, stress decisions, etc. The goal of the analysis section is a conversion of the input text to some sequence of speech segments. These segments may represent phonemes, diphones, allophones, etc. Although there is still much work to be done in the analysis section it is the synthesis section that we will be concerned with.

The synthesis process involves the conversion of the codes to sound. Many methods have been devised to address the synthesis of the speech signal from a set of stored parameters. Parametric synthesizers use a time varying digital filter whose characteristics are updated periodically to reflect changes in the speech signal. Other concatenative synthesis systems record sections of speech for later playback, stringing these sections to form words, sentences, etc. (2). All of these schemes must have the ability to compress the quantity of information needed to recreate the speech waveform.

Methods that attempt to reduce the amount of data necessary to store the speech signal by using waveform coding methods rely on certain characteristics of the waveform (correlation etc.). These methods typically exhibit a relatively low level of compression or loss of information or both. They typically are purely mathematical and are not based upon any particular model of the speech creation process (vocal tract modeling). These methods include PCM, ADPCM, CVSD, etc. If telephone quality reproduction of the original speech is the goal then we could point to the fact that the ANSI standard for ADPCM used in the public switched network has a minimum bit rate of 32 kbit/s (3).

Other methods use a technique of modeling the speech production process performed by the human vocal tract. These methods are typically called parametric synthesizers and include LPC and formant coding. LPC is a generic mathematical technique for approximating a waveform or function with a series fitted coefficients.

Formant synthesizers model the output of the human vocal tract. They reproduce the speech energy spectrum by modeling the resonances of the vocal tract. This is true for both voiced and unvoiced speech. Commercially available single chip formant synthesizers typically store the formant filter parameters inside the IC and group the parameters into phonemes or allophones not allowing the user access to individual speech control parameters such as formant frequencies and bandwidths, voiced/unvoiced selection etc. (4). The following describes the latest generation formant synthesizer that provides for direct manipulation of all speech parameters.

The PCF8200

The PCF8200, a single chip integrated circuit, allows the user to control pitch, amplitude, frame duration and frequency and bandwidth of up to five formants on a frame to frame basis. This results in a possible bit rate of between 500 and 4500 bits/s. At an average bit rate of 1500 bits/s speech quality is superior to 32 kb/s telephone ADPCM. This high level of data compression is a significant advance and could lead to many improvements in the area of communication aids.

Development of speech for the device is performed by playing a recording into a development system. The development system analyzes the speech and generates a data file in exactly the format that can be sent to the PCF8200 for playback. Before storing the data file the user may make alterations to any of the parameters and hear the results instantly. The data file can be stored in EPROM or other memory for later playback.

In actual applications, the user has control over the data file and may make changes to the file to introduce certain effects. Because of the low bit rate to the device, changes to the speech data can be made on the fly by most medium speed controllers. In the case of concatenative synthesis, this may involve smoothing of the speech output between consecutive sections of speech. With such simple control requirements, other problems such as applying pitch contours throughout phrases may be more easily addressed.

Applications

With its high level of data compression the PCF8200 is a single chip device that lends itself to many of the techniques now being used to synthesize unlimited vocabulary speech output. Users of waveform coding methods may find the level of compression to be higher than many single chip coders now available and could result in decreased memory requirements. Users of concatenative systems may find this device to be an effective tool to reduce the size of their diphone, phoneme or demi-syllable inventories.

Conclusions

Many devices using speech synthesis in a communication aid suffer from either high cost or large size or both. Although speech output contributes only one portion to the overall device it can dictate some of the most costly components of a communication aid. The PCF8200 with its low power consumption, high degree of speech data compression and low cost will prove to be a superior solution to the portable speech synthesis problem.

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Determining Future Software Requirements for Augmentative Communication Systems

P2.2

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Introduction

The development of a software architecture for augmentative communication systems could enable developers to cooperate in the future (Demasco, Ball, & Kerly, 1989; McDougal, 1989). In trying to develop an architecture that will successfully support a wide range of systems in the future, it is important to determine:

- Features of currently available systems that will continue to be valuable in the future,
- Capabilities that current systems are missing, and
- New capabilities that we might imagine in the future.

For this project, the analysis of future needs has proceeded along two paths. First, we have been pursuing an ongoing analysis based on discussions with clinicians in the field of augmentative communication. While it has been extremely useful to the project, this type of personal contact is limited in scope and is very informal. A more ambitious form of needs analysis is underway in the form of a needs analysis survey. This survey will help us reach a more diverse group of AAC users both in terms of geographic location and in terms of system experience.

Survey Design

The survey has been developed with four major design goals:

Identify needs - Help us assemble a shopping list of AAC system capabilities or attributes which are considered necessary or desirable by users (both clinicians and consumers),

Prioritize needs - Develop some feeling for the relative importance of the capabilities identified,

Evaluate design issues - Gain user perspectives on specific design possibilities or trade-offs that we are considering,

Encourage cooperation - Identify and establish contact with a user group with which we can collaborate in the future.

Furthermore, we want to encourage respondents to speculate about the future and to brainstorm with us about what might exist in the future. To achieve these goals, the survey contains a variety of question types including multiple choice, open-ended questions (e.g., "How might rate enhancement techniques be improved in the future?"), and proposed scenarios about which the respondent can comment.

The survey document is organized into five major sections. The first section, *Respondent Information* derives demographic information from the respondent including education, profession, and computer experience. The remaining four sections each cover a major system design issue.

Physical Interface - This section of the survey addresses system components related to the user's input. This primarily includes input devices (e.g., switches, joysticks) and selection techniques (e.g., scanning, direct selection).

Language Interface - This component of the survey addresses the variety of issues involving system vocabulary content, organization and presentation. This includes item characteristics (e.g., graphic representation), rate enhancement and vocabulary set customization issues. A sample question from this section appears in Figure 1.

System Output - This part of the survey covers all features of the system relating to output. This includes a variety of output modalities such as speech and print, as well as connection to other systems such as computer access and wheelchair control.

System Environment - The final section focuses on a wide variety of general system design issues. This includes documentation, customization, and the use of AAC systems for assessment and training. This section also includes some non-software components such as batteries and system size and weight. Although those questions may not be useful to our work, we believe that this information could be valuable to device manufacturers.

Survey Distribution

The intended target group for the survey is individuals who have experience using augmentative communication systems. This includes both professionals and consumers. The United States membership of the International Society for Augmentative and Alternative Communication (ISAAC) was selected because it includes both groups. While this group is not absolutely representative of the user population, we believe that membership in ISAAC is an indication of a strong interest in AAC.

Rather than directly mail the survey to the target group, we chose to send an initial mailing with a description of the survey and a reply card indicating a willingness to participate. This mailing was sent to the target group in the fall of 1989. Of the 1304 individuals contacted, we received 617 responses. Of those responses, 564 individuals expressed an interest in participating in the survey.

Current Status

Final revisions of the survey have recently been completed, and it is due to be mailed shortly. Data will be stored in a DBASE IV database. Analysis will be performed with the SYSTAT statistical package. Preliminary analysis should be complete by the summer of 1990. Conclusions drawn from the survey analysis will be used to enhance the architecture software design.

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Acknowledgments

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25. How desirable would these selection set capabilities be for future AAC systems?

	Not a Desirable Feature	Minimally Desirable	Moderately Desirable	Very Desirable	Crucial
a. graphic symbols generated on dynamic display (e.g. Blissymbols, Minsymbols, rebusses, etc.)	1	2	3	4	5
b. choices of color for symbols, text, graphics, backgrounds	1	2	3	4	5
c. flexibility in arrangement of text/symbols(e.g. in rows, column, quadrants,etc).	1	2	3	4	5
d. highlighting of text or display segments(e.g. message text, function symbols)	1	2	3	4	5
e. option to construct multiple overlays/levels	1	2	3	4	5
f. dynamic display	1	2	3	4	5
g. control of user access to certain functions or levels	1	2	3	4	5
h. display of communication system and other systems (e.g. environmental control unit, other applications/ programs).	1	2	3	4	5
i. ability to store large pieces of text	1	2	3	4	5
j. ability to store combinations of text/functions as individual selection items (e.g., speak, clear)	1	2	3	4	5
k. access to windows to display/hide additional functions/capabilities	1	2	3	4	5
l. other________________________________	1	2	3	4	5

Figure 1. Sample survey question

DEVELOPMENT AND EVALUATION OF A GRAPHIC-BASED MULTIPURPOSE COMMUNICATION AID: PROJECT COMPACT

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ABSTRACT

The development and evaluation of a multipurpose communication tool, called COMPACT, will be presented and the system will be demonstrated. The COMPACT is designed for individuals who need a voice output device, yet who cannot easily use spelling based devices or devices that we use a limited number of static symbols. The COMPACT incorporates high quality speech with a dynamic visual display. Speech is created using a sound digitizer to record natural speech. The visual display, a flat LCD panel, can present virtually any picture or graphic, including animation. The COMPACT can be easily customized to meet an individual's needs. Data from a modified case study approach involving two children and a comparison of the time required to develop individualized communication systems on the COMPACT and other communication aids will be presented.

INTRODUCTION

Some of the innovative features that are incorporated in the COMPACT are: dynamic visual display (LCD screen), high quality digital speech recording and output, on-screen help, extremely easy point-and-click communication "board" development system, selection from among a large number of prepared graphic images, creation of new graphics, automatic recording of responses, a simple artificial intelligence system for analyzing responses and providing reorganization suggestions, personal information displays, talking calculator, environmental control options, and software links to a wide variety of educational activities and tools. The system can be activated by direct touch, single switch scanning, mouse, and keyboard. When available, the entire software system will use erasable CD for storage.

SOFTWARE DEVELOPMENT

The COMPACT's software was designed using the powerful, yet user friendly, authoring/information management program called HyperCard™, by Apple Computer. HyperCard™ proved to be an excellent tool for developing the software since it can combine graphics and sounds and it provides an intuitive random access navigation system. Another advantage of HyperCard™ is that it enables software designers to rapidly develop working software that can be easily modified. The COMPACT's software is modular so that one component can be modified without necessitating a change to the entire system. In addition, links to other programs and tools can be made with only a few clicks of a mouse. Since HyperCard™ is widely available and easy to learn, the COMPACT's software can be be modified by other therapists and software engineers to better meet client needs.

CREATING AN INDIVIDUALIZED LANGUAGE SYSTEM

The COMPACT is designed to be intuitive and easy to use (simply point-and-click). The therapist uses four interrelated HyperCard™ "stacks" or mini programs to design and construct the language system. The resulting language system will itself be a unique stack; the therapist will be creating a sophisticated computer program without even knowing it. This system includes a process for digitizing and storing words, phrases and sounds, a process for using clip art and creating graphics, and a process for organizing elements (i.e., sounds, graphics, and buttons) onto electronic pages.

Data preparation involves a five stage procedure. The first stage is identifying the necessary data (i.e. speech, graphics, and text) that the client will use in the COMPACT. The second stage involves sketching out on paper the organization of the selection areas (buttons), speech (and sounds), graphics and text that will be displayed on each screen for the client. Numerous screens or pages will be prepared for each client. A single screen display is called a "page". Each selection area is called a button. "Pressing" the button by clicking on it with the mouse, or by touching the touch sensitive screen, or by stopping a scanner at that location will activate the button . The third stage involves digitizing the sounds and graphics. The fourth stage involves formatting or organizing the data (buttons, speech, and graphics) onto pages that will meet the specified communication needs. The final stage involves testing the system to ensure that it will meet the client's needs. Any of the elements (pages, buttons, sounds, and graphics) can be easily modified at any time.

Graphics generator

Each button on a page has the capability of having a unique graphic and text element associated with it. The therapist can select graphics or icons from the "Picture Warehouse". This stack consists of a large collection of electronically stored artwork and search functions. The therapist can also use scanned images and clip art. Graphics stored in "PictureWharehouse" automatically adjust to the size of the button. All of this is accomplished with a few clicks of the mouse. Another strategy for creating graphics involves drawing new pictures and modifying clip art with the tools supplied with HyperCard™ or any graphic art program.

Digitizing Sound

The MacRecorder™ by Farralon is used to digitize and store sounds. MacRecorder™ is a powerful, yet low cost and easy to use sound digitizer. MacRecorder consists of a hand-held digitizer/microphone that is plugged into the modem port and HyperCard™ based software, called HyperSound™, for storing and editing sounds. We have made some modifications to HyperSound™ to link it directly to other components of the COMPACT's management system. The HyperSound™ interface is similar to a cassette recorder. A related program, called SoundEdit™, enables the therapist to edit sounds. For example, the therapist can use SoundEdit™ to increase the amplitude of the passage and to eliminate unwanted background noises from the stored passage. The therapist can store a sound passage into a stack called "Sound Warehouse" for latter placement on a page, and the therapist can directly place the sound on a selected page and button.

Page Layout

This stack enables the therapist to design the layout of each page in the communication system. The first step in the process involves designing the button arrangement for each page. From 1 to over 35 buttons are available for each page. The therapist can design a custom button arrangement by simply selecting a template. Each page of a communication system could have a different button layout if so desired. The therapist can also reorder the pages in any manner desired. The entire process is accomplished by selecting items and their locations with the mouse. The program is designed to automate the process as much as possible. Numerous dialog and confirmation boxes are provided to assist in this process and to serve as a safety net in case of errors.

Response Recording and Analysis

One of most unique features of the COMPACT is its ability to record and analyze client responses. The COMPACT records the times and locations of all button activations. Intelligent software within the COMPACT can conduct a wide variety of customized frequency and sequence analyses of these data. Based on these analyses, suggestions are provided to the therapist for reorganizing elements in order to increase the efficiency of the communication process. This capability of the COMPACT enables therapists to easily determine the effectiveness of language instruction and other habilitative interventions.

Memory Bar

Another unique feature of the COMPACT is the graphic memory bar. Whenever a button is selected it will highlight (darken and flash) and a small copy of that graphic is placed in the memory bar across the top of the page to give a visual signal that it had been activated. The memory bar remains constant as the user moves from page to page so that items can be easily repeated, cleared, and to extend an utterance while in Store mode.

On-Screen Help

Detailed instructions for using the COMPACT and for creating layouts are always available by clicking on a Help ? button.

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AUGMENTATIVE COMMUNICATION SYSTEM UPGRADES WITH THE NONSPEAKING BRAIN INJURED INDIVIDUAL

P2.4

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ABSTRACT

The nonspeaking traumatic brain injured (TBI) individual requires implementation of temporary augmentative communication systems (ACS) during the acute rehabilitation phase. This is due to the individual's changing cognitive and physical status. This poster presentation will examine (1) types of ACS upgrades; (2) the frequency of upgrades and (3) factors which influence system upgrades.

Many changes occur during the acute rehabilitation phase in the nonspeaking TBI individual due to neurological recovery, medical intervention, orthopedic management and changing communication and environmental needs. To accommodate and facilitate recovery of cognition, language and speech, individuals go through several ACS upgrades over the course of his/her rehabilitation. These upgrades help nonspeaking individuals improve communication, meet cognitive and language goals and allow for better integration into the rehabilitation program.

Data from multiple case studies will be presented. These nonspeaking TBI individuals were studied from admission to discharge in an acute rehabilitation program and three types of system upgrade were closely examined:

1. Increasing system complexity via vocabulary expansion (e.g. increasing number of symbols or words).
2. Increasing symbol system complexity (i.e. gestures, words, alphabet).
3. Increasing system type complexity (i.e. boards, dedicated communication devices).

These upgrades were studied in terms of the frequency of upgrade and factors which influence system upgrades.

Findings from these case studies reveal: 1) System upgrades occur with the TBI because of changes in cognition, physical status and communication needs. 2) As cognition improves the need for expanded vocabulary is necessitated by changes in communication and environmental needs and treatment goals. 3) System upgrades (symbol and type) occur more frequently as cognition and communication needs change.

> i.e. In confused individuals progression from yes/no or choices to a symbol or word board tends to be due to cognitive improvement. However, when individuals are higher functioning changes in system type are due to changing communication and environmental needs.

Information gained in this presentation will assist clinicians in knowing when and how to upgrade ACS for the nonspeaking TBI in the acute rehabilitation phase.

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P2.5

FUNTION-INTEGRATION, REMOTE CONTROL, DUAL TOUCH SWITCH FOR THE DISABLED

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ABSTRACT:

A severely disabled patient suffering from brainstem CVA was admitted to our hospital. Although cognitively intact, she is non-vocal and has only limited control of her right thumb.

Due to the extreme severity of this patient's disability, she required a custom designed switch access system since no commercially available products were able to be used by her.

This presentation will describe the design and development of a Function-integrating Remote Control, Dual Touch Switch which enables the severely disabled patient, who is cognitively intact, to fulfill his/her basic daily needs - emergency calls, environmental control and augmentative communication.

INTRODUCTION:

Today's technology offers a variety of equipment for everyday needs in leisure and business. However, the disabled community is at a disadvantage. Rehabilitation engineers have contributed tremendously by modifying, adapting and designing dedicated equipment for the disabled. Since the demand for such modification is high and human resources in Rehabilitation Engineering limited, we found it necessary to design an easily adapted remote control programmable touch switch capable of operating directly, or through an environmental control unit, various pieces of equipment.

BACKGROUND:

A forty year old female suffered a right intracranial hemorrhage five years ago which required a right parietal craniotomy and evacuation of the hematoma, leaving her with severe brainstem dysfunction and associated quadriparesis, dysphagia, severe dysarthria, and visually impaired due to abnormal eye movements and cataract development. Since that time she has been monitored continuously by nursing home staff and is totally dependent in all activities of daily living. A recent medical report indicates that although she is non vocal, she is cognitively intact and has control (albeit limited) weak movement of her right thumb. There is also some evidence of psychological trauma which may be exacerbated by her inability to communicate and/or call for help when needed.

We classified her basic daily needs as:

a) emergency calls
b) environmental control
c) augmentative communication

The specifications of interfaced instrumentation needed to control the commercially available equipment are:

a) Dual switch system.
b) Programmable switching speed.
c) Orthotic mount.
d) Remote control.
e) Audio and visual feed back.
f) Battery operated.
g) Minimum power consumption.
h) A switch with a long life.

Despite a thorough examination of the market for an instrument suitable for this patient, nothing was found. Each of her needs listed above could be met by a commercially available switch or control unit but nothing met our specifications for an integrated capability controlled from a pair of capacitance touch switches operated by her thumb.

SYSTEM DESCRIPTION:

The following components were developed to achieve the features specified above:

Orthosis: A cast of the patient's right hand and forearm was taken. A mold was made to accommodate the free movement of the thumb, encapsulating the wire and securing the touch switch, and bearing the weight of the transmitting control unit.

Transmitter control unit: This small part contains all the electronics and the power pack. The electronics are designed in modules for flexibility in expansion and/or adaptation for different applications. The major modules incorporated in the system are:

1 - Capacitance dual touch switch: a capacitance dual touch switch was designed in preference to a resistive touch switch as skin resistance changes considerably from day to day.

2 - Dedicated programmable logic electronics: this module is built of

digital logic and multiplexers with a hardware timing program which permits changing the speed of operation as the patient progresses in using the system.
3 - Power saving unit: this module monitors the operation of the patient. Should activity stop for a period of time predetermined by the therapist, the system shuts down (all except the touch switch module) in order to save power in the transmitting unit.
4 - Switches module: this contains a set of five long life relays operated by the programmable logic. This module controls the ultrasound frequency in the transmitter.
5 - The ultrasound module: this module has a preset frequency for communication with the receiver unit to operate main powered units.
6 - Power sensor module: it was found necessary, during the later stages of development, to have a power sensor to assist the patient in determining battery condition.
7 - The audio feed back module: four different tones are generated in this module. Three of these are for switch A and one for switch B.
8 - Visual feed back module: This module contains an array of LED positioned to indicate the operational channel. This has been incorporated for the patient's aide and for future applications.

The receiver control units: These units are commercially available (Tash Inc., Ontario) and have predetermined frequencies to operate for each selected channel as a dual switch.

OPERATIONAL PROTOCOL:
The system has two switches A&B mounted on orthosis facing each other on a ring surrounding the thumb.

Touching switch A powers the system and locks into channel one. This channel is dedicated to drawing attention from patients in the surrounding area and/or calling a nurse at the nursing station.

Touching switch A continuously for 4 seconds will scan the four channels and produce a different tone for each of the first three channels and a pause for the fourth.

Releasing the switch at the desired channel locks the operation in that channel.
The two switches A and B become the operator of the channel; B for any desired lengthy pulse (such as scanning) and A for a pulse shorter than B (such as "select").

To exit from the channel, touch switch A continuously for four seconds and this will cause the system to scan the channels again.

If activity stops for the preprogrammed period (two minutes is recommended for saving battery energy), the system will shut down.

Proposed channel operation:
Channel one for drawing the attention of those in the immediate area and/or alerting the nursing station (switch B will sound a buzzer beside the patient and activate the switch to call a nurse).

Channel two to operate the ECU (switch B to scan the ECU and A to power on/off the instrument).

Channel three to operate the morse on the computer (Augmentative Communication System) switch B for the dash and A for the dot.

CONCLUSION:
This Function-integrating, Remote Control, Dual Touch Switch was designed and built to assist a severely disabled patient who had a brain stem CVA. The patient is typical of many who are severely disabled yet cognitively intact. Our evaluation and analysis showed that the major needs of such a patient are the emergency announcer, environmental control and augmentitive communication. The clinical evaluation of the system showed the device to be successful with the patient mentioned above and we plan to expand its use.

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P2.6

TECHNOLOGY IN THE CLASSROOM: APPLICATIONS AND STRATEGIES FOR THE EDUCATION OF CHILDREN WITH SEVERE HANDICAPS

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Increasing the integration of assistive device technology in the classroom would provide the opportunity for close to 4.5 million children nationwide to reach their educational potential. *Technology in the Classroom: Applications and Strategies for the Education of Children with Severe Handicaps*, has been designed to facilitate this opportunity.

Three self-instructional modules will be developed, field tested, and disseminated that will train special educators, including classroom teachers, speech-language pathologists, occupational therapists, physical therapists, and audiologists as well as families to effectively use appropriate assistive technologies in a variety of educational settings. Emphasis will be placed on the implementation of educational programs within the least restrictive environment using an interdisciplinary approach.

INTRODUCTION

The purpose of the Technology in the Classroom project is to develop, field test, and disseminate three self-instructional modules designed to improve the knowledge and skills of special educators, including classroom teachers, speech-language pathologists, occupational therapists, physical therapists, and audiologists as well as caregivers so that they can effectively integrate assistive technologies into the educational programs of young children ages two to seven with severe handicaps.

The three modules will be designed to bridge the gap between theory and practice by providing videotaped examples of exemplary practices in the integration of assistive technologies in educational programs. The videotape for each self-contained module will be accompanied by supporting print materials.

The three module topics are 1) Educational Curriculum; 2) Communication; and 3) Mobility. The Educational Curriculum Module will stress the importance of providing greater accessibility to the educational curriculum using assistive technologies as instructional tools. The Communication Module will cover the use of augmentative and alternative communication as well as the use of communication aids, techniques, and strategies with children who are severely speech impaired and others who may benefit from communication training. The importance of independent mobility to the personal and educational development of the child will be addressed in the Mobility Module.

Experts from special education, speech-language pathology, occupational therapy, and audiology who are experienced in the use of assistive technologies with young, severely handicapped children will develop the modules. The three modules will explore strategies for selection and use of a variety of assistive devices, including computers, communications aids, assistive listening devices, switches, environmental controls, and powered mobility systems. The role of play as a significant learning tool for young children as well as assistive technologies that provide access to play will be incorporated.

The first draft of the modules will be ready by June 1990. The packages will then be subjected to national peer review by interdisciplinary special education professionals, service providers, and consumers. The modules will be field tested at both the local and national levels to validate their effectiveness in advance of a national dissemination program.

EXTENT OF NEED AND EXPECTED IMPACT OF PROJECT

Technology, appropriately selected and used, can mitigate the limitations that many disabilities impose, making it easier for children to have access to and achieve some control over their learning environment. Applications of current technology in educational settings can result in dramatic changes in the quality of life and learning of young, severely handicapped children.

The goal of the Technology in the Classroom project is to increase the effective utilization of assistive technologies by severely handicapped children in the classroom to help them reach their educational potential in the least restrictive environment. To meet this goal, the project will address the critical need for training facilitators to integrate these technologies into the educational curriculum. Simply providing computers, communication aids, electronic wheelchairs, assistive listening devices and environmental controls to children does not ensure their use. Effective training strategies must be incorporated into the school activities by knowledgeable teachers, clinicians, and caregivers if children are to benefit.

There are two primary variables that impede the implementation of effective strategies in this area: 1) Many special education professionals and caregivers lack training in the use of assistive technologies; and 2) Students lack access to appropriate technologies. If implementation strategies were integrated into the educational plans of these children, "close to 4.5 million children nationwide" could have the opportunity to "reach their educational potential through the use of assistive device technology which will enable them to maximize their learning capabilities" (Congressional Record, 1987, [1]).

ROLES FOR PROFESSIONALS

This project's training modules reflect a philosophy that recognizes that someone (ideally the classroom teacher) must manage an assistive technologies program so it can be integrated into the curriculum and other activities within educational settings. Participating professionals, support personnel, and caregivers will be provided with strategies that enable them to function effectively on an inter-disciplinary team.

SPECIAL EDUCATION PROFESSIONALS: THE NEED FOR TRAINING

If technology is to have the desired impact on teaching and learning, educators and clinicians must be comfortable with assistive devices as tools that enhance, rather than interfere with, their daily teaching and other responsibilities (Office of Technology Assessment, 1988, [2]). While research and recent advances in technology have provided a wealth of information applicable to children with severe handicaps, the transfer of information from research findings to educational applications continues to be ineffective (Ourand & Gallagher, 1988, [3]).

There is a clear need for a nationally focused program designed to successfully implement assistive technology strategies. This project will directly address these needs by providing a high-quality, self-instructional program designed to develop the expertise of special education professionals and families in implementing successful educational programs for children with severe handicaps.

ACKNOWLEDGEMENTS

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P2.7 INTERFACING PIEZOELECTRIC/PYROELECTRIC SENSORS FOR USE WITH COMMUNICATION DEVICES

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ABSTRACT

The interface of a patient with a communications apparatus is accomplished to greatest advantage by a simple mechanical switch. When a mechanical switch can not be operated, however, an electronic sensor must be adapted. Piezoelectric and pyroelectric sensors have become popular, but their signal requires amplification. By using voltage feedback, we have designed an amplifier with very high input resistance. This enhances the low frequency response of the sensors. A device based on this design was successfully used by two patients.

INTRODUCTION

The interface of a patient with a communications apparatus, be it a nurse call system or a computer, is accomplished to greatest advantage by a simple mechanical switch. A more sophisticated mechanical switch is sometimes necessary, examples being a sip or puff, a blow, a membrane, or a specially designed lever or push button. The electrical circuitry in all these instances is uncomplicated. When a mechanical switch can not be operated, however, an electronic sensor which requires more complicated circuitry must be adapted.

Piezoelectric and pyroelectric sensors have become popular. Unlike strain gages and various proximity switches, they do not require an excitation voltage. Their major disadvantage, however, one which they share with all other electronic sensors, is that their signal requires amplification. We have been working recently with a product, KYNAR (1), which has both piezoelectric and pyroelectric properties, i.e. the voltage generated is proportional to both mechanical deformation and changes in temperature. This paper pertains to the electronics required for applying this product to patient use.

BACKGROUND

Unlike most other piezoelectric/pyroelectric materials which are rigid crystals or ceramics, KYNAR is a very flexible plastic film. Its surface is usually metalized to allow electrode contact. It can be cut to almost any size or shape with a razor blade or sharp shears.

One equivalent circuit is shown in Figure 1 in which E is the voltage generated by either stress or heat, C is the capacitance formed by the material and its surface metallization, and R is the input resistance of the

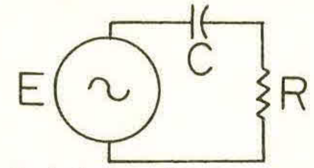


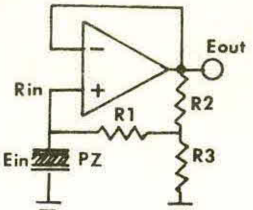
Figure 1. Equivalent circuit.

amplifier. This forms a capacitive coupled circuit. Its low frequency response is determined by the time constant of R and C. Since C is determined by the geometry of the sensor and the type of film used, it is fixed for a particular sensor, leaving R as the only variable.

The sensor configuration that we have employed has a capacitance of 0.0015 MF. The time constant resulting from a 10 megohm to a 22 megohm input resistance of the interfacing amplifier is sufficiently long for most applications. However, for detecting a quicker action, a one megohm resistance and shorter time-constant should be used and for an unusually slow action, 50 or more megohms may be appropriate. Such high values of input resistance are difficult to obtain. Operational amplifiers with field effect transistors at their inputs do have extremely high input resistances. However, their advantage is lost because their inputs must be referenced to ground through resistors for stability. The largest standard resistor is 22 megohms; beyond this value special or precision resistors are required which are expensive and difficult to obtain.

METHODS

Through the use of positive voltage feedback, the effective value of an input resistor can be made to be many times its actual value. This is accomplished with the circuit shown in Figure 2. This circuit differs from a standard voltage follower in that the input resistor R1 is returned to a voltage divider R2 and R3 at the output rather than to ground. The simple equation



$$R_{in} \cong R_1 \bullet \frac{R_2 + R_3}{R_2}$$

Figure 2. Postive voltage feedback circuit.

shows how the high effective input resistance is obtained. Since the positive feedback is always less than unity, the circuit is stable, i.e., it will not oscillate. However, when the feedback is sufficiently close to unity, the amplifier can latch up as if no resistance were applied to the input. This latch up is caused by the offset voltage and current as well as other imbalances in the amplifier. In actual use, one adjusts the feedback to obtain the desired response from the sensor rather than measuring the value of the effective resistance. If a multi-turn potentiometer is used as the feedback control, the input resistance can be varied from the actual value of R1 to many times that value.

RESULTS

Our best applications have resulted from using the material's pyroelectric property. The circuit was designed to be activated by the heat of a patient's breath. The patient was a quadriplegic individual who could not use any of our existing switches. The switch worked well when the patient was sitting in a chair. It was less reliable when the patient was in bed. Apparently, when the patient sat, there was enough circulation of air around the sensor to keep it at room temperature. When the patient was in bed, body heat reduced the temperature gradient between the room and the patient's breath, rendering the switch much less sensitive.

The second use of this device was as a touch heat sensor. For various reasons, this patient could not effectively use any of our other switches. Moreover, the volume of exhaled breath was insufficient to operate the device as originally designed. The patient's head motion, though limited, was sufficient nevertheless to activate the sensor by touching it with his cheek. Although the pressure of the cheek was insufficient to generate a piezoelectric voltage, the heat generated a voltage by pyroelectric effect.

DISCUSSION

Our circuit affords flexibility in the design of piezoelectric/pyroelectric based interfacing devices. It allows the various characteristics of the sensor to be tailored to a particular patient. If a patient has best control with fast actions, low input resistance and short time constants can be designed. If movements are slow or the generation of sufficient heat takes time, large input resistance is required. The output of the amplifier can remain high as long as one or two seconds when the sensor is subjected to a constant pressure or heat source. Limited proportional control is also possible with additional circuity. Any of the piezoelectric or pyroelectric materials can be used, whether they are crystal, ceramic, or plastic.

CONCLUSIONS

A simple and inexpensive circuit has been described which capitalizes on the advantages of piezoelectric and pyroelectric sensors tailored for controlling communication devices. Two practical examples of its applications are cited.

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P2.8

DEVELOPMENT OF A COMPUTER-BASED EXPERT SYSTEM FOR THE SELECTION OF ASSISTIVE COMMUNICATION DEVICES

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ABSTRACT

This research project aims to develop a computer-based expert system which will aid in the selection of one or more assistive communication devices for a client. The process by which the human expert knowledge is organised into a form suitable for the computer application is described and an example of a derived rule is given. The current status of the project is that a user answering a number of questions will be referred to none, one or some of 13 communication devices. An indication of the future development and availability of this expert system is discussed.

INTRODUCTION

The use of an electronic assistive communication device by an individual usually comes about as a result of deliberations by a speech pathologist, in conjunction with the client and others in their communication environment.

The use of expert systems is a relatively new area. It has been proposed that this new process has application in the prescription of assistive communication devices. This project is a step towards evaluating whether or not this is true.

We believe that an expert system developed around the knowledge of personnel at the Centre could do three things: assist in matching a device to the needs and abilities of a particular client, assist in the training of therapists who might need to prescribe an electronic assistive communication device, and provide therapists with a checklist for the processes involved in prescribing a device.

It is particularly important in a location such as Australia, remote from the major manufacturers of communication devices, to obtain access to expert knowledge to assist in the selection of a device to try with a client. It can be time-consuming and expensive to return one device and obtain another one on loan. The system attempts to narrow the field and reduce the chances of this occuring.

MATERIALS

An expert system is a computer program which incorporates elements of artificial intelligence to provide human-like problem-solving within a specific knowledge domain. The program consists of two main parts (i) the knowledge, facts, rules which make up the field (called the knowledge base) and (ii) a mechanism by which the inference process is applied (called the inference engine).

The software used for this project is the MS DOS Texas instruments package Personal Consultant Plus.

DEVELOPING THE KNOWLEDGE BASE

The current version of our expert system contains information on the following 13 devices: Zygo Portable Anticipatory Communication Aid (PACA), Zygo Talking Notebook, Light Talker, Touch Talker, Intro Talker, WOLF, RealVoice, Parrot, Parrot-JK, Toby Churchill Light Writer, Canon Communicator, Technical Solutions Voice Synthesiser Unit and any microcomputer with word-processor and printer. The 17 features that we consider to be critical in selecting a device are shown in Table 1.

Table 1

users symbol system
input method
selection technique
output required
vocabulary size
vocabulary manipulation
portability required
price range acceptable
spelling ability
target size
vocabulary environment
vocabulary expansion capability
vocabulary flexibility required
visual acuity
visual interpretation skills
speed and accuracy
training availability

These features are prompted for, with the user selecting a response from choices presented on the screen, e.g. "Does the client require a device with a voice output?" Choices are "face-to-face", "over-the-phone", "no". The user may select one or more responses. The expert system then applies rules which incorporate these parameters to determine the goal of device selection. This is the process of consultation.

The rules have a condition or premise to which is attached a consequence or action. There are currently 56 rules. As an example, part of rule 9 says

IF :: symbolsystem = traditional orthography and input capability = normal keyboard and selection = direct and speech = face-to-face or speech = no and portability = by hand orportability = wheelchair tray or portability = stationary only or portability = portable and notetaker ! = has-inbuilt-printer

THEN :: device selection = ZygoTNB and Print "A suitable device is the Zygo Talking Notebook"

If all the features of a premise are satisfied, the program will carry out the action part of the rule, which in this case is to say that the Zygo Talking Notebook is an appropriate device. If there is more than one suitable device, then all are listed. If there is any uncertainty in response, then that uncertainty is reflected in the screen statement for the device selected e.g. if the user had indicated that it was only 80% certain that the input capability was normal keyboard, the device would be ZygoTNB (80%).

PILOT RESULTS

Trialling of the system has been limited to the speech pathologist within the team, two other speech pathologists and a rehabilitation engineer. With a particular client in mind, the speech pathologists consulted the expert system and then compared the result with their own selection. A match was found for approximately 50% of the consultations. This early trialling has revealed errors in the translation of the expert's knowledge to rules in the system. The corresponding corrections to the system are underway, along with modification to the expert knowledge base. Additional testing and modifications will occur early in 1990.

DISCUSSION

We believe that the expert system we are developing will be used in all of the categories usually associated with expert systems.

(1) to **assist in the process** of matching an assistive communication device to the needs of a client, a task which would demand a lot of attention of an 'expert' in the field.

(2) as a **job aid** in training therapists in the processes involved in making a match between client needs and an assistive communication device.

(3) as an **apprentice system** which aids the 'expert' in providing the appropriate assistive communication device.

CONCLUSION

Expert systems have a role to play in the fields of Rehabilitation and Special Education, however they are only as good as the rules encapsulated in the system. With experience and additional research, efficient techniques will be found to match available devices to clients. This research has clarified and captured some of the rules, and is expected to enable the expertise to be easily shared with other expert and non-expert workers in the field.

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A Software Object Library for Augmentative Communication Systems

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Introduction

The increasing complexity of computer and microprocessor based communication systems necessitates greater software engineering efforts on the part of developers. A standard software architecture provides the opportunity for AAC system developers to cooperate in their design efforts and be more productive in bringing products to the market. In a previous paper (Demasco, Ball & Kerly, 1989), we suggested an object-oriented approach to an AAC software architecture. This would define the system in terms of the objects which model the real world problem, and the connections between those objects. We have implemented that approach with the development of two functionally independent components:

- A software object library that contains all of the system objects,
- An interpreted authoring language that defines the overall system operation and provides the connections between objects (Ball and Demasco, 1990).

This paper discusses our implementation of the software object library which we call LASO (Library of Adaptable Software Objects) and provides a detailed example in the **device** object, which is one of the class hierarchies in LASO.

LASO General Description

LASO was developed with the following major design goals:

- Each component (e.g., device) should be usable independently of other major components.
- Hardware dependent code should be isolated from classes when possible, and within classes when not.
- The system should be extensible in the future without major restructuring of the overall system.

To these ends, we have designed LASO to be a collection of C++ objects organized in functionally independent class hierarchies. In addition, there is a common library that contains:

- General purpose C++ classes (e.g., collection classes),
- C procedures for common functions (e.g. error reporting),
- Hardware specific interfaces (e.g. the display).

Each component of LASO is implemented as a C++ class hierarchy. Two major components have been designed and implemented. The **item** class provides support for a flexible vocabulary set structure. The **device** class supports both input and output devices.

Device Class Hiearchy

In our design, we sought a powerful way to express the concept of a device. Specifically, we wanted to support a number of flexible features that were expressed in our own system requirements as well those stated in McDougal et al., (1988). These include:

- Support for multiple I/O streams
- Ability to define I/O device combinations
- Easy Inclusion future devices
- Flexible user control over device parameters

We believe that these goals have been met in the design of the class hierarchy (shown in Figure 1) for the **device** object. This hierarchy consists of an "abstract" base class with two major derived classes. In the figure, each class is represented with a single rectangle that contains the class name and a list of the methods (i.e., functions) for that class. Each derived class inherits both data (not shown) and methods from its ancestor.

Device Class - A device is modeled as a fixed collection of "channels" that can be referenced either by a channel number or name. Values are read from a channel with the `get` method and are written with the `put` method. Any channel can be queried to check if it's state has changed since the last `get` call with the `isChanged` method In addition, a method called `nextChanThatChanged` provides an efficient mechanism for querying the state of the entire device. Finally, internal data items such as device name and number of channels are accessed through query methods

Physical Device Class - This class is derived from the device class and functions as an "abstract" class for specific device implementations such as **IBMjoy** and **sunConsole**. Typically, a channel corresponds to some physical characteristic of the devices. For example, a standard two button mouse is represented with four channels: horizontal location, vertical location, left button state, and right button state. The physicalDevice class represents the most efficient (but least flexible) way to access the system hardware.

Logical Device - We have added flexibility to the design through the concept of logical device. A logical device is similar to a generic device in that it consists of a collection of channels. It differs in that each logical device channel is "attached" to a physical device channel. This approach allows us to dynamically construct a device from one or more physical devices.

There are currently two ways to construct a logical device. In the first method, a logical device is declared and a number of calls to the method `defineChan` are made. Each call to `defineChan` specifies a logical channel number to be added, a name for that channel, the physical device to be attached to, and the specific channel number of the device. For example, the code to construct a logical device that provided horizontal cursor movement from a head pointing device connected to the mouse port, vertical cursor movement from one axis of a joystick, and selections from any key on the keyboard would be the following:

```
logicalDevice myIn("myDevice", 3);
myIn.defineChan(0,"IBM-MOUSE",X, "X");
myIn.defineChan(1,"IBM-JOY",X,"Y")
myIn.defineChan(2,"IBM-KBD",KEYS,"SELECT")
```

The second way to define a logical device is to use the `read` method to obtain a device definition from a file. This provides the capability to define new logical devices without writing code. The above example could have easily been defined in a file and read in by the system at run-time. This capability provides the opportunity for clinician or user defined devices to furthe the overall system flexibility.

Conclusion

LASO continues to evolve as the current implementation is tested, and new design ideas are added to it. Near term goals include implementing more physical devices, as well as the definition of a "filtered" device class. In addition, new class hierarchies (e.g., rate enhancement) are currently being developed and will, upon completion, be added to the library. Finally, we expect to release a version of LASO (as well as the authoring language "Adapt") in the fall of 1990 to other developers for evaluation.

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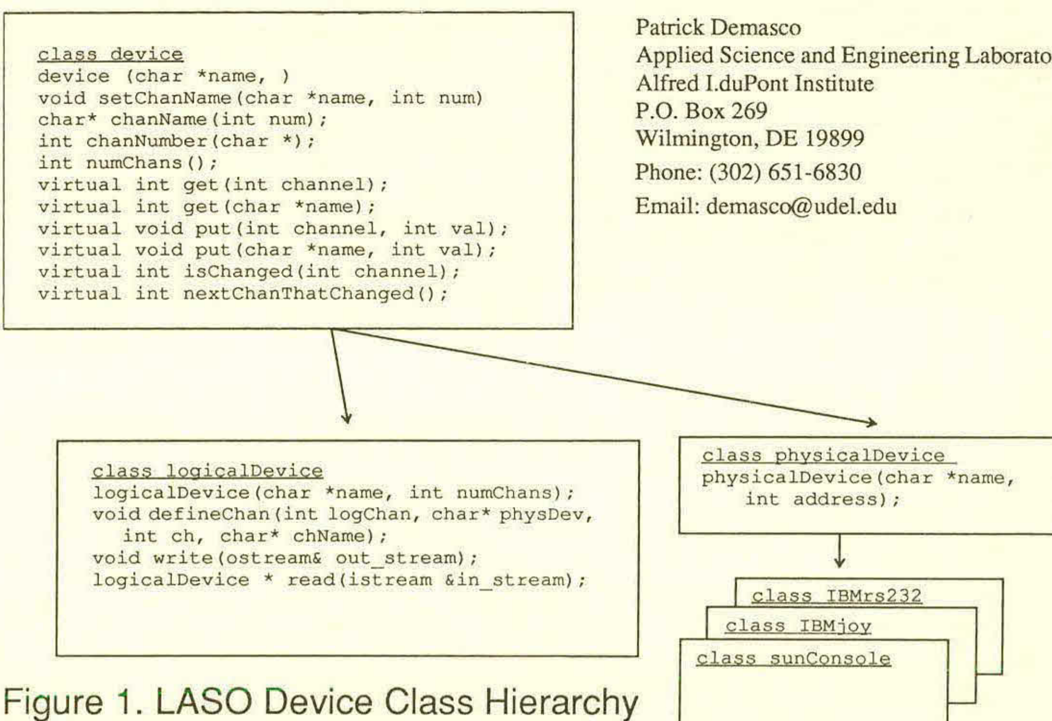

Figure 1. LASO Device Class Hierarchy

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INCORPORATING MULTIPLE ASSISTIVE DEVICES INTO A COHESIVE SYSTEMS

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ABSTRACT
As technology advances many individuals are able to utilize a number of assistive devices to gain independence. This paper will present three case studies addressing the issues, problems and solutions encountered when incorporating multiple individual assistive devices.

INTRODUCTION

Commercially available assistive technologies act as a catalyst for independent living. Various devices begin to allow independent access to mobility, communication, and environmental controls to disabled individuals. When incorporating multiple assistive devices into a cohesive system it is necessary to do so without compromising the goal of independence. It is the unique needs of each individual that makes this a challenge. Extensive evaluations are required for determining the exact devices to best enable maximum individual independence. How these devices interact with one another creates unique circumstances requiring further intensive evaluation.

ISSUES

When it is apparent that a number of individual devices will be required the following issues must be addressed as they often create complications.

1.) Optimal operating positions
   - One location for several devices
   - Interference of operation of another device
   - Safety of the device and individual
   - Interference with architectural access
   - Is device mobility required

2.) Will the system create dependence?
   - All on/off switches accessible
   - Inhibits full capabilities
   - Interference with transfers
   - Alternatives for system failures
   - Interchangeability of devices

3.) Affect of individuals habits
   - Aggressive behavior
   - Obsessions or habits
   - Daily living accessories
   - Interference with recreation

4.) Aesthetically pleasing
   - Individuals appearance obstructed
   - Adverse appearance due to complexity

5.) System Complexity
   - Set-up and removal complexity
   - Probability of damage to system or individual with alternative removal technique
   - Ability of staff to trouble shoot

CASE STUDIES

CASE A

CASE A INCORPORATES
- A joystick controlled power wheelchair
- A Light Talker with printer accessed by optical light sensor
- A manual communication board accessed by right index finger

PRESENTING COMPLICATIONS
- Range of motion prohibits access further than four inches from body
- Manual board obstructs use of Light Talker - Communication systems obstructed view of individual
- Requested visual access to printer
- Interchanging between communication and driving
- Access to all wheelchair controls
- Two additional switch sites
- Mounting system must allow quick removal

SOLUTIONS
The complete system is mounted on and recessed into a laptray. The joystick and additional switches are mounted on the left side of the tray. The manual board is mounted vertically on a spring-loaded hinged ABS board positioned on the right side near the body. This allowed access to the manual board by pushing a lever. The Light Talker is mounted in a motorized case positioned on the right side behind the manual board. The motorized case positioned the Light Talker in the optimal location for communication while

allowing the capability to lower it from view for driving. The small motor is operated by a single toggle switch. When the communication mode is selected the motor moves the Light Talker into position and the wheelchair becomes inactive. The printer is recessed into the tray. The printer cover is clear plexiglass. It is located in the upper left corner of the tray. To remove the system the optical light sensor and the joystick need to be disconnected. Then, the tray can be slid off.

CASE B

CASE B INCORPORATES
- A joystick controlled power wheelchair
- A Touch Talker with printer
- A Canon Communicator
- Environmental controls including- radio, lamp and T.V. access from bed and wheelchair
- Regular access to a glass of liquids
- Access to recreational activities

PRESENTING COMPLICATIONS
- The Canon, Touch Talker, glass and recreation activities must be operated from the same location
- Limited range of motion with left hand
- No use of right hand
- Leg spasms
- Request visual access to printer
- Interchangeability between Canon, Touch Talker, glass and recreation activities
- System cannot obstruct vision for driving
- Additional on/off switch for printer

SOLUTION
The joystick is mounted with standard equipment from left armrest. Touch Talker is recessed into the laptray left of midline directly in front of the body. To prevent bumping during leg spasms the seating system required lowering into wheelchair. The printer is recessed in the right center of the laptray with a clear plexiglass cover. A T.V. remote control is velcroed to an ABS wedge on the left between the Touch Talker and the joystick. A switch for the printer is mounted on the wedge below the remote. The Canon is mounted on a pivoting bracket. It is positioned under the T.V. remote wedge. By pulling a hook the Canon pivots to an upright slightly tilted position resting above the upper left corner of the Touch Talker keyboard. The glass is positioned in a swinging holder. The swing arm pivots from the right side. The arm can swing inward to position the glass midline above the Touch Talker. The last six inches of the laptray is clear plexiglass to allow optimal view for driving. When the assistive devices are not in use a clear area remains on the laptray for other activities such as eating and reading. It was concluded the lamp and radio control did not need to be operated from on the wheelchair. Two remote switches are mounted on the bedroom wall at the height of the joystick control and accessible from the left side. Two additional switches are mounted on the left side of the bed. The T.V. remote can be removed from the wheelchair for use in bed.

CASE C

CASE C INCORPORATES
- A walker
- A Touch Talker

PRESENTING COMPLICATIONS
- The Touch Talker imbalances the walker
- Access to Touch Talker while walking and sitting
- Due to aggressive behavior individual must not be able to remove Touch Talker
- Touch Talker cannot interfere with walking

SOLUTION
The Touch Talker is positioned vertically in ABS case. The case is mounted securely in the center of the walker with the top of the Touch Talker equal to the top of the walker. The case has a flip-up lid for protection while allowing access to the keyboard. The walker is counter balanced with small weights in the rear legs.

CONCLUSION
With the continued expansion of technology it is increasingly the rule rather than the exception for individuals to utilize incorporated systems. These systems create unique issues which must be considered prior to purchase to insure maximum independence with minimal complication and expense.

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Design and Assessment of an Integrated Wheelchair Tray System for Augmentative Communication

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INTRODUCTION

In recent years, many new and innovative communication approaches and devices have become available to augment the communication of a greater number of non-speaking physically disabled persons. These devices, as well as other conventional augmentative communication approaches (e.g. graphic displays) are effective only if they are easily accessible by the user (1). To ease accessibility for wheelchair users, often a communication system is mounted on a wheelchair tray which facilitates trunk and hand control and serves as a surface for work, play, and feeding (2). A customized approach is often necessary because commercially available trays neither readily adapt to most communication devices nor do they provide features required by most users of communication devices. The cost of fabricating and fitting these individualized trays is high as labour, both clinical and technical, is intensive.

This paper reports on the development and assessment of a new wheelchair tray system which is intended to meet the multi-purpose needs of most physically disabled users requiring augmentative communication systems.

DESIGN REQUIREMENTS

The design requirements for the prototype tray system include the following:

i) The tray system must be stable and have smooth surfaces and corners;

ii) The tray must be designed to accommodate a range of graphic communication devices;

iii) The tray must be provided with a hinged distal section to allow its adjustment to incremental angles to facilitate eye gaze and listener-assisted scanning communication systems;

iv) The tray system must have a simple and expedient means for adjusting the height and elevation angle of the tray;

v) Customization of the proximal section of the tray to facilitate trunk and hand control should be possible;

vi) A single tray system should be easily interchangeable between a manual and a powered wheelchair for users having more than one mobility base;

vii) The tray system must be lightweight and durable in everyday use and during inadvertent collisions;

viii)The tray system must permit the tray surface to be stored safely and easily at the side of the wheelchair;

ix) The tray system must be mountable on the major types and sizes of manual and powered wheelchairs without the need for excessive modifications;

x) The tray system must have provisions for accommodating a variety of powered wheelchair controls;

xi) Provision and fitting of the tray should be economical.

DESIGN DESCRIPTION

The tray consists of two sections: a distal portion which is sized to accommodate commonly-dispensed communication devices/displays, and a proximal section which can be customized to accommodate various trunk sizes and contours. The distal part is a laminate consisting of a moulded Kydex surface and a polycarbonate honeycomb core for lightness. To cushion the tray, an integral lip reinforced with high density polyethylene foam is provided. The proximal section, also a Kydex laminate but with a plywood core, supports the hardware for mounting the tray to the wheelchair. A thin, thermoformed clear copolyester cover is provided.

Interconnecting the two tray sections is a pair of independent hinges which allows, through the rotation of thumb screws, the distal section to be tilted and locked at any angle above the horizontal relative to the proximal portion. The tray can also be folded and stowed beside the chair without removing it. For clients who do not require the fold-away option, moulded plastic mounts which slide onto the wheelchair armrests are also provided.

METHODS

Seven subjects, five years to twenty-nine years of age, participated in the clinical field trials which were of no less than 6 weeks duration. Four subjects lived at home and three lived in institutional settings. All presented with a primary diagnosis of cerebral palsy, spent the majority of their day in a wheelchair, and required the use of an augmentative communication system. One subject used a voice output communication aid and a Blissymbol display, while the remaining subjects used only graphic communication displays. Subjects were chosen due to a perceived need for a tilted tray and/or a mounting device which would allow for storage of the tray beside the wheelchair.

For each subject, two questionnaires were completed by each of two primary caregivers. Both a pretrial and posttrial questionnaire were completed to evaluate the performance of the subject's original tray and the prototype system, respectively. The questionnaires were designed to elicit information about equipment used by the subject in his/her wheelchair, activities of daily living for which the wheelchair tray was used, and a variety of functional and technical factors relating to the experience of both the subject and caregivers in using the tray.

RESULTS AND DISCUSSION

In general, respondents reported that the tilt feature was extremely useful and easy to use. Results of responses regarding handling of the tilt mechanism are graphed in Figure 1.

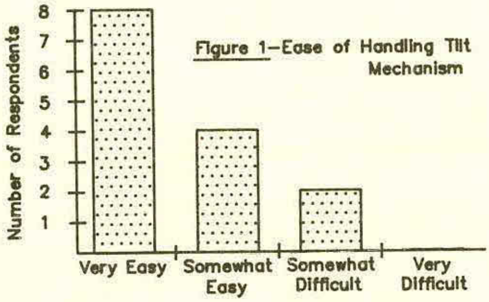
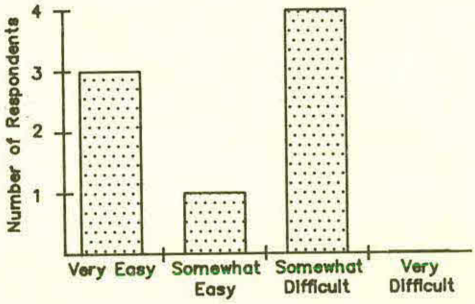


Figure 1—Ease of Handling Tilt Mechanism

For the four tray systems provided with a fold-away mechanism, caregivers were generally satisfied with its operation. Problems reported related to insufficient instruction on operation of the device. Supportive documentation would therefore be needed to accompany a production version of the tray. Results of caregiver responses regarding handling of the fold-away mechanism are shown in Figure 2.

Figure 2—Ease of Handling Fold-Away Mechanism



Respondents reported that the prototype trays were lighter and less bulky than their original trays. They also noted improvements in aspects related to hygiene, moisture protection, and aesthetics.

The overall success of the prototype system became apparent by its acceptance at the conclusion of the clinical field trials. All respondents expressed a desired to continue using the system rather than resume using the original tray. However, one subject preferred his previous flat tray because requesting a caregiver to level his tray before he could drive his electric chair decreased his independence.

CONCLUSIONS

Results of the evaluations suggest that the prototype tray system was well received by caregivers and clients. The tray system was found to be durable and safe to use and the tilt feature appeared to facilitate user access to communication systems. The fold-away option was also found to be useful.

With the provision of a variety of distal tray modules, the production tray is expected to offer a functional arrangement which will closely conform to the needs of most physically disabled persons requiring an augmentative communication system.

ACKNOWLEDGEMENTS

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Design of an Exercise Machine for Spine Flexibility

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Introduction

Back pain is experienced by many people due to fatigue, excessive lifting or sudden motion. Rehabilitation often involves relaxing and exercising the back muscles to increase their flexibility and strength. Heat and gentle massage may relieve painful back spasms and lessen pressure on the nerves that go into the shoulders and arms. Spine flexing, combined with certain arm and leg exercises, lead to a quicker recovery and reduce the risk of further injury. The goal of this work was to develop a simple machine that provides all these rehabilitation treatments, and this paper presents its design.

The Design

The Spine-Flex machine consists of five major components (see Figure 1): (1) frame, (2) bed, (3) back lifting system and (4) arm exercises and (5) leg exercise mechanisms. The bed is flexible and forms a smooth curve when the lifting mechanism is activated (Figure 2). The spine bending angle is pre-set by the user, through a sliding switch on the side of the frame, with a maximum allowable of 40°. The flexible section that supports the lumbar region of the spine is made of a polymer that allows the bed to bend. Rollers installed on each corner of the bed frame allow the curvature. The mattress consists of foam rubber and is equipped with a heating pad and a massager. The controls are operated through a small hand held unit.

The back lifting system is mounted on the frame underneath the flexible section of the bed. As shown in Figure 3, it consists of (1) electric motor, (2) gear box, (3) power screw and (4) lifting block. The motor drives a worm gear which in turn drives a vertical power screw. The rotation of the power screw drives the lifting block upward. The top surface of the lifting block is a smooth curve designed to support the lower back region. The flat edges on the lifting block are designed to minimize tensile stresses on the polymer section of the bed.

The leg exercise mechanism is designed for flexion motion (up and down) as presented in Figure 4. Resistance is produced in the downward direction only, whereas raising the legs to the vertical position is done against their weight only. The desired resistance in the downward motion is achieved with a pulley system attached to a damping cylinder. The damping cylinder is a self-contained hydraulic cylinder that utilizes a piston with an orifice hole and a uni-directional valve. The resistance

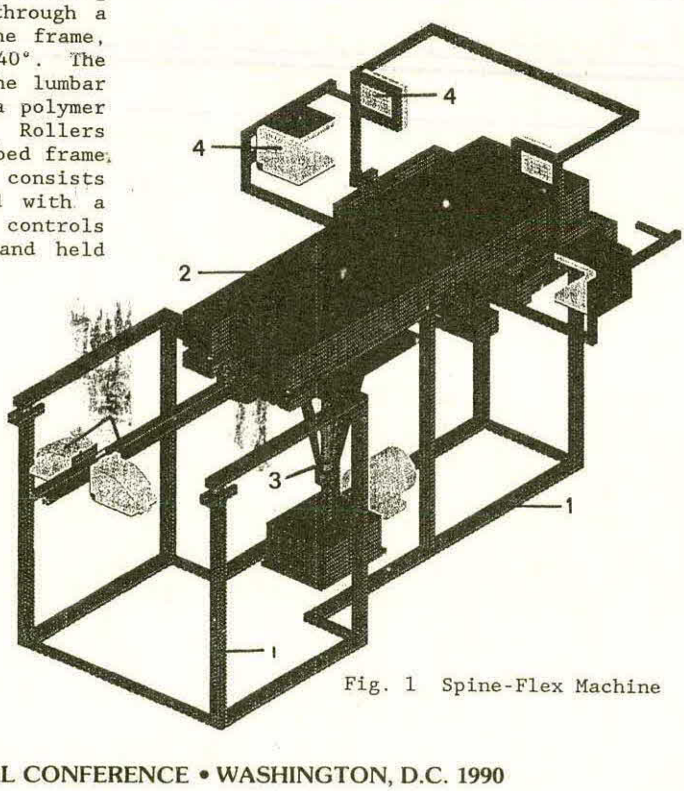

Fig. 1 Spine-Flex Machine

(between 0-100 lb) depends on the speed of motion. The pulleys were necessary to satisfy the force limitations of the cylinder.

The arm exercise system provides for the "fly" and "pullover" exercises, each with a separate mechanism for its desired motion (Figure 5). Both mechanisms are linked to rack and pinion gears and damping cylinders to deliver the desired bi-directional resistance.

The arm and leg exercise mechanisms were designed for different size patients. The positioning of the mechanisms was determined considering the rotation axis for each exercise and the space limitations of the machine. The pads were designed to accommodate different body proportions.

Concluding Remarks

The proposed design has not been tested yet. The next stage in the development of the Spine-Flex machine is a prototype testing. This is necessary in order to verify the design and assess its value and contribution to rehabilitation.

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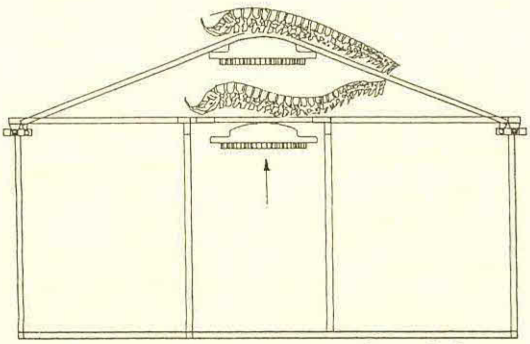

Fig. 2 Flat and Bent Back Positions

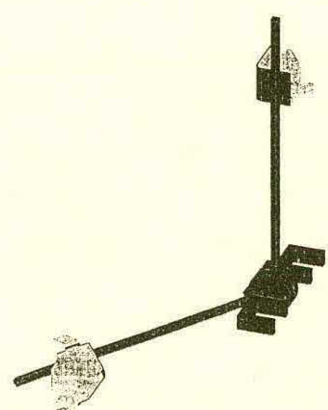

Fig. 4 Leg Exercise Mechanism

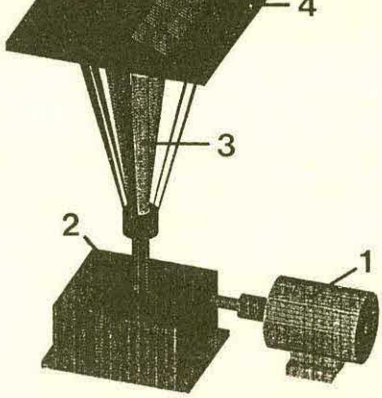

Fig. 3 Back Lifting Device

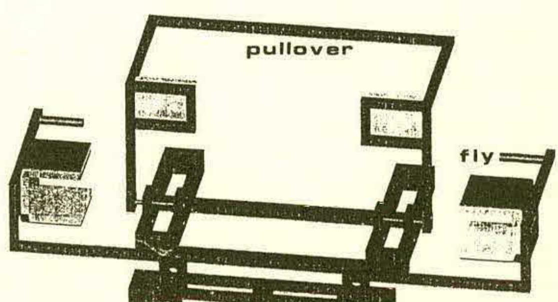

Fig. 5 Arm Exercises Mechanisms

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DESIGNING LOWCOST ELECTRONIC MUSIC INPUT DEVICES FOR HIGH LEVEL QUADS

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Abstract
This paper highlights observations of a unique research project to design, build and test innovative musical input devices for persons with high level quadriplegia (HLQ). Beyond the engineering requirements for these latest technology devices, we examine how designing aesthetic devices for the physically disabled is influenced by other factors, specifically the psychological and sociological factors that form the disabled person's support environment. Our approach is to work with a 4-member team of high level quads who participate in the entire design and testing process.

The paper discusses the role and interaction of the individual with the available technology while considering his support environment. The results and the devices designed can be seen on video tape (1).

1.0 Introduction

Our experience, this past year, in designing innovative music input devices for disabled persons has exposed us to the complex issues and considerations which influence the design process as it applies to the disabled community. In this strongly institutionalized milieu centered on illness, the disabled world is emerging as a microcosm where the large hierarchical ins-titutions come into contact with small and agile high technology organizations. This marks a dynamic and turbulent frontier where enabling devices can and do alter the lifestyle of disabled persons and, consequently, their definition of, need for, and acceptance of social support.

The physically disabled have a greater openness to and acceptance of technological devices than the general population. This makes progress within the disabled milieu a precursor to what will happen in the next twenty years as the general population of North America experiences the physical disabilities associated with aging. Important keys to achieving and maintaining independence are well-designed, innovative input devices, conceived and implemented with input from disabled persons.

While disabled persons cover the entire spectrum of human needs, wants, likes, and dislikes, as a group they have some special characteristics that set them apart from the able-bodied community. They each depend on a support environment that must accept the freedom that can be gained through technology. It is difficult and counterproductive to approach design for high level quads armed only with an understanding of what works for able-bodied persons. Designing effective devices for HLQs can best be done with their direct participation.

2.0 The Support Environment

The disabled person's support environment is a complex collection of interactions, services, programs, and systems which influences the disabled person (Figure 1). The importance of the support environment is that it shapes the disabled persons expectations, interactions, and behaviour. The total institution presents the greatest challenges for the design process.

DISABLED PERSON
+
SUPPORT ENVIRONMENT
(which includes caregivers, structures, institutions, health care organizations /programs, and family)
+
ENABLING TECHNOLOGIES

FIGURE 1. A 3-PART MODEL OF THE DISABLED PERSON & HIS SUPPORT

The home portion of the support environment is where the disabled person lives: whether or not it is in an institution (e.g. a hospital); or in a group home; or in their own homes. The institution brings its own agenda and rules which may differ from public perception (2).

From conversations with HLQs, the attitude, quality, and attention they receive from care-givers strongly depends on their control of the caregiver hiring process. Programs and services also vary in availability, relevance, and quality. Clearly one of the more frustrating problems is transportation. Residents of institutions may have access to the institution's own trans-portation but they may be restricted to going only on those outings which the institution approves.

All of these factors strongly influence the HLQ's feedback and response to devices design for them.

3.0 Participatory Design

Disabled persons who are involved in decisions which affect them, their home environment, and their mobility are able to have the kind of systems and environment that serves them best, supports their physical well-being and reinforces their own self-esteem. The same is true disabled persons who are in on the design of innovative input devices. The engineer or designer who recognizes this will produce more successful (for him and his disabled clients) devices.

This type of participatory process forces engineers to see their own stereotypes and realize the special requirements of the disabled. Typical experiences are discussed elsewhere (3,4,5).

Disabled persons form the single most important source of information about their own condition and what works and does not work for them. In the design process, they must be included from the beginning. It is often necessary to spend a great deal of time familiarizing the disabled person about the technology and techniques available today, but the effort is worth it.

For example, in designing musical devices for the disabled, it is important to identify members of the disabled community who are interested in music and who can work with on the design as consultants. It is important to also identify the relevant technologies available, (e.g. computers, microprocessors, microcontrollers) as well as the appropriate standards that apply (Musical Instrument Digital

Interface - MIDI, safety). And finally, the devices must be placed in the social, cultural, and artistic environments in which they will be used. The HLQs on this project have subjected our designs to two months of field testing so far with much useful feedback.

Microprocessor and microcontroller chip technologies now make so much more available at a reasonable cost to assist the disabled to be more independent and to interact more freely with their own environment. We make heavy use of microcontrollers (especially the Motorola MC68HC11 family) in designing MIDI electronic music input devices for persons with HLQ.

4.0 Conclusions

Engineering design of aesthetic and cultural devices for "live" music performance must adher to technical design constraints. In designing for HLQs, we recommend a participatory design process, involving the physically disabled from the start. Various socioogical and psychological factors, however, exist which will inevitably affect the participatory design process, the successful realization of a working device, and success of the disabled person and the use of their device in performance. Although technology has increased the independence of disabled persons, the focus to date has concentrated on the lower most of Maslow's hierarchy of needs (food and shelter). Self-esteem, artistic expression, and self-actualization are now being examined, and technology provides the means to develop the tools, systems, and devices required by disabled persons to achieve their own personal goals in these areas. Unhappily, residents of total institutions are less able to access the new technology or be involved in the development of tools, systems, and devices than are their non-institutionalized counterparts.

5.0 Acknowledgements

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One Handed Paper Managing System

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Introduction

In the course of working with several clients the use of only one hand, the problem of paper management has come up several times. Problems with holding paper for writing, stapling and paper cliping. The problem of just getting papers lined up for further processing. These problems were the bases for developing this paper management system.

Method

This system is composed of an edged base, an over arm lock down and insertable stapler and punch components. The base 'is made of formica covered plywood with a no slip bottom. It has two sides edged with ABS plastic to allow a person to slide papers into these two edges to align tnem. The corner where these two edges would meet is cut away to allow papers to protrude for paper cliping, stapling or punching. The inserts for stapling and punching lock into this recess also.

The punch and staple inserts are standard punch and staplers mounted on blocks which locks them in place at the correct heights. These units are easily slid in with one hand.

The over arm lock down is a stainless steel tube positioned over the bases with an over center lever with a rubber foot on its bottom end.

This foot holds paper for writing, stapling, punching and paper clipping. This over arm unit is adjustable for different thickness of papers and different tensions.

Conclusion

This is a simple device that can be extremely helpful with paper management and can be easily modified for an individual client. Its weight and construction make it very stable.

Acknowledgement

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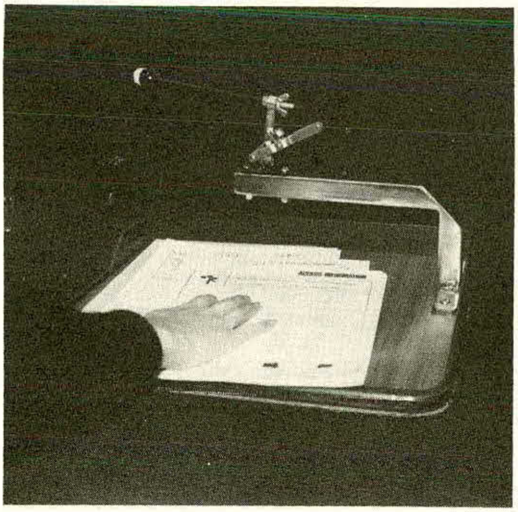

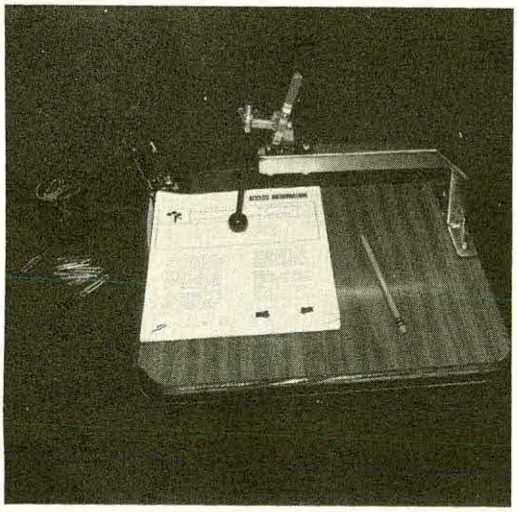

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ABSTRACT

The University of Wisconsin-Madison began a preservice technology training program in 1988, which by June 1990 will be completing its second academic year. The overall model has been presented previously (Smith et al., 1989; Smith & Christiaansen; 1989). This paper specifically reports on the experiences and knowledge gained from the first and second years of this curriculum. In particular, two types of data have been collected from students to ascertain the extent to which they are benefitting from the program. In addition, the annual meeting of the TechSpec Advisory Panel has provided comments to improve the TechSpec model and its curriculum. Both of these sets of information should be of benefit to technology training programs which are just developing or to existing technology programs which are updating or revising their content or format.

OVERVIEW OF TECHSPEC

TechSpec is an interdisciplinary instructional model focused on occupational therapy students during their basic professional training. The program functions as a specialization certificate curriculum, similar to four others already available to occupational therapy students at the University of Wisconsin-Madison (Gerontology, Music Therapy, Dance, and School Certification). The program has a two-level design: some students receive foundation level training while others train to a specialization level. Both are elective tracks. However, students who elect to take the specialization direction commit themselves to 26 semester credits, of which 12 are already required for occupational therapy students and 14-18 are technology core and elective courses which must be completed before the Technology Specialization Certificate is awarded. The curriculum includes several introductory courses in assistive and rehabilitation technology, as well as a field work requirement. A set of competencies to be acquired is specified. In general, however, it is expected that graduates of this program will have the elemental understanding of assistive and rehabilitation technology applications and the basic skills to move into a specialized assistive and rehabilitation technology setting. There, they would be expected to gain substantial on-the-job training. It is not expected that a technology specialist graduating TechSpec will be ready to "hit the ground running" in any specialized area within assistive and rehabilitation technology. For example, a graduate will not be immediately capable of serving as a specialist in interfacing, seating and positioning, mobility, robotics, etc. They will, however, have received an educational background that makes it much easier to absorb increasingly specialized information about technology. This background will enable them to become more proficient through subsequent specialized fieldwork and on-the-job training.

In addition, this program is producing a set of teaching workbooks/guides for other curricula. These resources are being made available at cost to other faculty, curriculum planners, and projects through the Trace Center's Reprint Service.

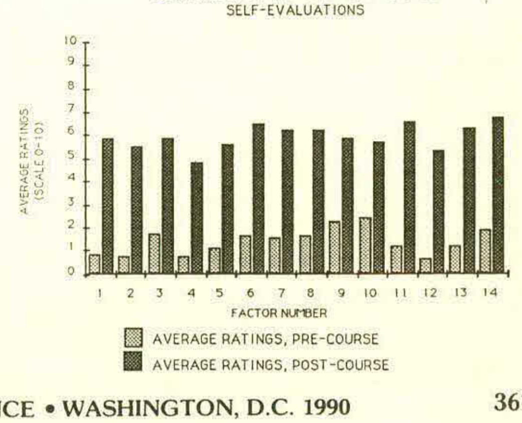
FINDINGS AND PRODUCTS TO DATE

Courses Taught

Six courses are taught specifically out of the TechSpec program on annual academic cycles. During the initial year, 48 students enrolled in the "Introduction to Assistive and Rehabilitation Technology," 28 in the "Design of Technology for Persons with Disabilities," 42 in "Adaptation and Construction of Equipment for Persons with Disabilities," 14 in "Microcomputer Software Applications in Occupational Therapy," 12 in independent study products, and 7 in fieldwork practica. Similar enrollment data are expected in subsequent years, although the hope is that class size will moderate after the initial influx.

Program Evaluation Results

A set of specific evaluation components are integral to this project. One is the assessment of the perceived knowledge and comfort of students. This subjective rating scale covers 14 different areas of technology. Students are asked to rate, on a scale of 0-10, their level of comfort in applying these areas of technology. This self-assessment rating scale is given to all students in the occupational therapy program as they enter their junior year, and readministered at the end of each semester, and at the completion of the TechSpec program for specializing students. The impact of the course "Introduction to Assistive and Rehabilitation Technology" is highlighted in Figure 1. As can be seen, the students' self-assessment is significantly increased



between the beginning of the course and the end of the course. The TechSpec project staff were also happy to see that even at the end of the introductory course, students were demonstrating that there remained substantial room for further skill building and knowledge acquisition. The self-perception rating scale data also highlight the impact of the progression of TechSpec courses on students' perception of their abilities. The data displayed stepwise increases of perceived abilities with each technology course taken.

A third comparison was made, of the TechSpec students' self-perception scores with the non-TechSpec students' self-perception scores. It revealed substantially higher ratings from the TechSpec students.

The occupational therapy students involved in the TechSpec program, as well as those who were not, also completed a 25 question multiple-choice test, focusing on their knowledge base in assistive and rehabilitation technologies and their application. In all cases, scores from the subjective test showed trends and differences similar to those described with the subjective data.

TechSpec Advisory Panel

Advisory Panel members expressed belief that the TechSpec program was benefitting the students, and that the program had moved into an up-and-running condition very quickly during the initial two years. The Advisory Panel also produced a list of suggested improvements, which provide some generic advice to not only this TechSpec program, but technology curricula in general.

Two major themes seem to run through the suggestions for improvement. The first was that training individuals to become competent technologists is extremely difficult and requires a long-term process. The second is that a program should focus on teaching not only technology and application outcomes but more on the detail of the process of evaluating, selecting, and applying assistive and rehabilitation technologies. Some of the specific ideas identified by the Panel are listed in Table 1.

Course Guides

Four course guides and publications have emerged from the TechSpec program, for use by other curricula. These include a course guide for the Introduction to Assistive and Rehabilitation Technology, a guide for the practicum courses, an overview of the TechSpec program, and a chapter introducing technology and its applications, appearing in a textbook aimed at advanced occupational therapists. (This chapter is used as one of the introductory readings.)

SUMMARY

In summary, the TechSpec program has moved very quickly in its initial two years. The program staff believe that the program has been successful in meeting its goals. However, the program has also encountered some frustrations and barriers in assistive and rehabilitation technology education. It continues to be the hope of the program staff that the program will not only provide direct training to students at the University of Wisconsin, but will provide resources and experiential comments which will be valuable to other curricula.

Table 1

- Consider optimal sequence of courses.
- Add the basic computer introductory course to the requirements.
- Encourage additional fieldwork experiences.
- Improve coverage in the areas of technology which are weakest in the current curriculum.
- Emphasize distinction between technology and technology applications (equipment versus technique).
- Limit enrollment in program, or secure funding for additional resources.
- Involve students more heavily in course design.
- Submit courses for formal University listing.
- Encourage University support, and move off grant funding.
- Add course content on documentation and reporting of assistive and rehabilitation technology interventions (assessment and documentation of efficacy of intervention).
- Increase time spent on ethical issues surrounding technology applications.
- Implement technology terminology earlier in the curriculum.
- Increase emphasis on technology user.

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Computer-Assisted Notetaking for Hard of Hearing People

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Introduction

Computer-assisted notetaking (CAN) is a technique that uses off-the-shelf technology to provide hard of hearing people with enhanced access to meetings and lectures.

Meetings and lectures are among the most frustrating of communicative experiences for many hard of hearing people. Each situation brings its own unique cluster of problems. During lectures, there is not much opportunity to interrupt for clarification if the hearing impaired person loses the thread of the talk. In group meetings, verbal exchange is usually rapid and it is difficult for a hard of hearing person to locate the speaker and orient himself or herself auditorally and visually before the person begins to speak. If an assistive listening system is provided, the microphone must be passed from speaker to speaker, and people forget to do so; often the hard of hearing person is reluctant to remind others to pass the mike, for fear of being a burden. Sometimes assistive listening systems are subject to interference or dead batteries, rendering them ineffective.

For these reasons, it is often difficult to provide high quality communication access to hard of hearing people, who vary in their ability to hear and understand in particular situations. Teachers, employers, and meeting planners cannot be certain that hard of hearing participants have correctly received the content of the meeting or lecture.

One solution to these problems is to provide some form of visual access to the spoken word. Real-time captioning (RTC) is sometimes used for this purpose. RTC employs trained courtroom stenographers to create verbatim captions of the entire transaction, using a special computerized system that translates the stenographer's codes into English text in real-time. RTC can be sustained at speeds of 200 words per minute, if necessary.[1] The transcript can of course be saved on disk and edited for dissemination. However, RTC is prohibitively expensive for ordinary daily use, costing roughly $1,000 per day, and is in short supply in many areas of the country.

Description

Computer-assisted notetaking is simply the use of computer technology to provide live notes during a meeting or lecture. A typist types as much as possible of the spoken content of a meeting on to computer keyboard and these notes are displayed on a screen or monitor. Depending on the skill of the typist and the speed of the speech, the output can vary from summary notes to near-verbatim captions.

Computer-assisted notetaking has to date received little attention, at least in the United States, but consumer interest in text-based access to meetings has grown along with consumers' increasing awareness of captioning technology; and the widespread availability of moderately priced computer projectors has made this application far more attainable than in the past.

The technique is proving extremely popular among hard of hearing people who have seen it. While demonstrating CAN at meetings of hard of hearing people in 1989, we distributed questionnaires to participants to gauge their opinions of this service. The 103 people who returned the survey varied greatly in degree of hearing loss, from mild to profound. More than 80% reported watching the notes, and all of those who watched said they were helped by the notes, with 67% rating the notes as "very helpful" and 31% describing them as "somewhat helpful" (with 2% non-response). Of the 20 people who did not watch, six could not see the screen from their seats, ten said they were able to hear the speaker well, and four said the notes distracted them from lipreading the speaker.

Computer-assisted notetaking can be used in a variety of settings--at conferences, lectures, workshops, and meetings. In the workplace, notes can permit hard of hearing employees to participate more fully in meetings. As with real-time captioning, the notes can be saved on disk and edited. Employers can read the notes following a meeting to check on the content relayed to their staff; hearing, hard of hearing, and deaf colleagues can benefit equally from a printout of the resulting notes.

Hardware, Software, and Personnel

Equipment and software requirements are flexible, varying according to the situation in which the notes will be employed. At a cost of as little as $250, a low-end home computer with inexpensive word processing software and a small television functioning as the display may suffice for gatherings where only one or two hard of hearing people are present.[2] In office settings, an office microcomputer and monitor could likewise be used for small groups.

For larger groups, a computer projector is an excellent tool for sharing the notes with many people, by displaying the content on to a wall or screen. When a computer projector is coupled with a laptop computer, computer-assisted notetaking is both portable and easy to use, although the cost will be higher--at least $2,500 for hardware and software.[3]

Keyboard macro software, which automatically expands abbreviations into full words, phrases or sentences, can be used to increase typing output and to reduce the number of abbreviated words that consumers must read. Such software is now inexpensive and easy to use. Some vendors feature versions that emulate stenography systems that some secretaries have learned for taking dictation. We are using PRD+ and find it useful for adding abbreviations in the last minutes before a meeting or lecture.

Researchers at the University of Bristol in England are developing several utilities tailored to the application of

CAN. These utilities are now in prototype form but may become commercially available in 1990. Features include control of the display to eliminate scrolling, which can be visually disturbing; a means by which prepared text can be displayed as it is spoken and sections deleted and or added whenever the speaker deviates from the prepared remarks; and a mixing box to permit the text and speaker's image to be displayed at the same time.[4]

Regardless of the equipment being used, the amount of detail provided in the notes depends on the skills of the typist and the speed of the speech. The notetaker must have the ability to type well (at least 60 words per minute), a good command of written English, and the ability to summarize information. Skilled secretaries, people who work as writers/editors, and interpreters who can type well are good candidates for the function of notetaker. Special training is unnecessary (although as the users of this service grow in sophistication, it may become necessary).

Practical Suggestions

There is no standard for practice of CAN, and procedures will vary according the situation and the consumers being served.

The first concern should be that consumers can see and comfortably read the text. (When we asked consumers for suggestions on how to improve CAN, improvements in the physical set-up were most frequently mentioned.) Screens and monitors should be free of glare or excessive ambient light; dimming the lights but providing a spotlight on the speaker works well. Placement of a projector screen should be as close as possible to the speaker. Placement of a monitor should be in line of sight with the speaker, if feasible.

The letters should be large enough to be easily read by hard of hearing users of the CAN service. We have found, for group meetings and lectures involving 30 to 80 hard of hearing people, that setting the display to 40 columns and using all upper-case letters produces an acceptably large image. Of course, margins and spacing must be adjusted to the individual circumstance.

The next concern should be that the notetaker can hear and perform without fatigue. The notetaker should be seated away from any interfering noise (such as the fan from the overhead projector). At many meetings involving hard of hearing people, amplification systems using FM or infrared transmission may be available, in which case headsets will be worn by users. If one of these headsets can be provided to the notetaker, then the notetaker can function without regard to ambient noise or background conversation.

If notes are being provided for a meeting lasting more than one hour, it is helpful to have a second notetaker available to share the work. If at all possible, the notetaker should be briefed in advance on the content and special vocabulary and proper nouns to be used in the meeting or lecture.

Occasional typographical errors seem to be tolerated reasonably well by consumers, and abbreviations are also tolerable and even desirable where they permit faster output. The style of notetaking will vary with the needs of the people using the notes. Some hard of hearing people prefer to use the notes only to keep their place during a meeting and prefer notes taken in outline form--short phrases that highlight the topic of discussion. Other individuals who have more difficulty following the speaker rely more heavily on the notes and want more detailed information provided in complete sentences.

The notetaker should take care to type the name of each speaker prior to a summary of that person's statement during meetings. If speech is rapid, the notetaker should not hesitate to summarize; however all attempts should be made to convey jokes that are made in the meeting or lecture. It is very discomforting to see and hear laughter all around and not be able to share the moment.

Conclusion

For many settings in which hard of hearing people are participants, computer-assisted notetaking can be a valuable means of access. Because of its low cost, ease of production, and high acceptability to hard of hearing consumers, it could become a major computer-based tool for people with hearing loss.

1. For more information on real-time captioning, see the following papers: Hutchins, J., "Real-time captioning: the technology" and Oliver, J., "Real-time captioning: training and employment." Both papers appeared in Harkins, J. & Virvan, B. (eds.) (1989), *Speech to Text: Today and Tomorrow: Proceedings of a Conference at Gallaudet University*. GRI Monograph Series B, No. 2. Washington, D.C.: Gallaudet Research Institute.

2. The Association of Late-Deafened Adults (1027 Oakton, Evanston, IL 60202) has prepared materials on low-end configurations of hardware and software for computer-assisted notetaking.

3. At the Institute for the Handicapped in Stockholm, researchers are completing a comparative evaluation of computer projectors for their efficacy in this application. More information can be obtained from Gearhart Elger, Handikappinstitutet, Box 303, S-161 26, Bromma, Sweden.

4. Dr. James Kyle, University of Bristol, personal communication, January, 1990.

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TRAINING RESPONSES OF SCI INDIVIDUALS TO FNS-INDUCED KNEE EXTENSION EXERCISE

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ABSTRACT

This study was conducted to evaluate the training effects of functional neuromuscular stimulation (FNS)-induced knee-extension (KE) exercise in spinal cord injured (SCI) individuals. A specially constructed chair was used for FNS-induced KE resistance exercise. Seven SCI subjects trained 3 x/week for 12 weeks using a progressive load resistance protocol. Following training, maximum load was significantly higher (mean 5.7 vs 10.2 kg), thigh skinfold thickness significantly lower (mean 20 vs 15 mm), and knee range of motion significantly increased (mean 125 vs 140 degrees) for the SCI subjects ($p<.05$). Pre- and post-training measurements of thigh girth, body weight and bone density were not significantly different. This FNS-KE exercise appears to improve the strength of paralyzed quadriceps muscle, improve knee range of motion, and retard the expected rate of bone loss. This form of FNS training of the quadriceps may be appropriate in preparation for more strenuous FNS activities.

INTRODUCTION

Recent innovations in functional neuromuscular stimulation (FNS)-induced exercise equipment have provided spinal cord injured (SCI) individuals with the option of exercising paralyzed lower extremity muscles [1-3]. As use of this equipment becomes more widespread, health professionals need to know about the rehabilitation benefits and potential limitations of these exercise devices [4]. Of particular concern are those devices which offer the option of strengthening because of the disuse osteoporosis which accompanies paralysis [5]. Past studies have shown that paralyzed muscles atrophy and that FNS of these muscles can improve muscle strength and endurance [6]. In addition, long-term use of FNS has been identified as a possible deterrent to the bone loss which occurs after SCI [7]. If FNS exercise improves the health, physical fitness, and the potential for rehabilitation of SCI individuals, then safe and effective testing and training protocols must be developed that can be readily used by rehabilitation professionals. The purpose of this study was to compare the pre- and post-training effects of FNS-induced KE exercise using specially developed testing and training protocols.

METHODS

Subjects were seven SCI individuals (one f, six m, lesion level range from C6 to T11 , X $\pm$ SD: age = 38.9 $\pm$ 11.0 yrs, time since injury = 7.0 $\pm$ 6.6 yrs, height = 176.9 $\pm$ 8.1 cm, weight = 69.9 $\pm$ 10.3 kg). One subject (#7) completed training, but did not complete post-training testing. Following informed consent, all volunteers for this study were medically screened to identify any contraindications to participation in exercise.

Pre- and post-training measurements included knee range of motion (ROM), thigh skinfolds, thigh girth, body weight, and maximum knee extension load. Trabecular bone density was measured at the distal tibia using a specialized quantitative computed tomography technique [8]. The chair and electrical stimulator system used for FNS-induced KE exercise has been previously described [9]. This system enabled asynchronous left-right KE exercise through approximately 70 degrees at a rate of six contractions/leg/min. Each subject was tested to determine the maximum KE load and the initial load to be used for training. For this test, KE exercise was performed for five repetitions starting with zero load and progressing in 0.5 kg increments to a maximum of 15 kg. Because disuse osteoporosis may markedly decrease bone strength, the maximal load allowed was 15 kg [1,10]. Pre- and post-training measurements were statistically compared using paired t-tests with a .05 significance level.

Each subject trained 3 x per week for 36 sessions using the following protocol for each training session. Each leg was passively stretched (passive knee extension) for 10 repetitions. A load equal to 1/4th of the maximum level achieved during pretesting was then used for 30 repetitions of FNS-KE. After a five min rest, the exercise was repeated. After another five min rest, the load was reduced by one half, and the exercise continued for 60 repetitions or to fatigue. When the subject was able to complete three consecutive sessions of this protocol, the load was increased by 0.5 kg to a maximum of 15 kg.

RESULTS

Each subject increased their resistance load over the 12-week training period, although the rate of progression differed among individuals (Fig. 1). Pre- and post-training measurements are shown in Table 1. Maximum load was significantly higher and thigh skinfold measurements were significantly lower following training. Knee ROM improved significantly, primarily due to increased knee flexion (pre-training mean 126 degrees vs post-training mean 142 degrees). Tibial bone density measurements for two subjects with long-term injuries did not change. However, two subjects who had been injured for two years or less demonstrated a slight decrease in bone density.

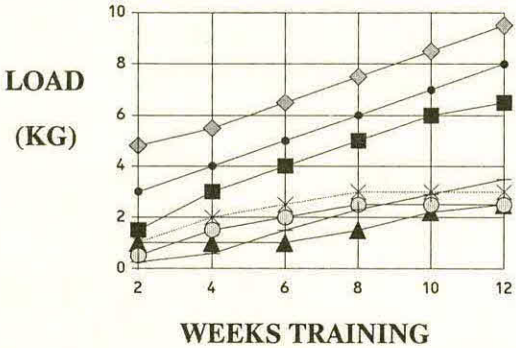

Figure 1. Knee extension load (kg) over the 12-week training period for each SCI subject (N=7).

TABLE 1: Means and standard deviations for responses to FNS-assisted knee extension exercise training (N=6).

	Pre-training	Post-training
Maximum load (kg)	5.7 (2.3)	10.2 (3.4)*
Thigh skinfold (mm)	20.0 (15.5)	14.5 (9.6)*
Thigh girth (mm)	46.4 (4.8)	46.0 (3.5)
Body weight (kg)	70.4 (12.4)	69.5 (11.4)
Knee ROM (deg)	125.3 (14.5)	140.0 (9.1)*
Bone density (g/cm^3) (N=5)	0.23 (0.092)	0.22 (0.085)

*Significant at the .05 level

DISCUSSION

FNS-KE exercise provides both concentric and eccentric conditioning against gravity and against additional progressive resistance. The maximum resistance load used in this study (15 kg) during pre- and post-testing appears to be well within safe limits for SCI subjects. Improved knee ROM may aid in the prevention of joint contractures, and may allow easier performance of activities of daily living. The exercise is beneficial for strength and endurance of paralyzed muscle (i.e. local, peripheral changes). The decrease in thigh skinfolds without change in bodyweight or thigh girth suggests an increase in thigh musculature or decrease in subcutaneous fat or fluid content (edema) of the thigh skin. This finding suggests that FNS-KE training may have beneficial effects on body composition.

Although bone loss was evident in the more recently injured subjects, the magnitude was substantially less than would be expected based on previous cross-sectional studies of spinal cord injured subjects [5]. In our previous study, a bone loss rate of 0.15 g/cm^3 was apparent in the first two years after injury. This rate is much higher than the highest bone loss rate in the present study (0.02 g/cm^3 per year). This suggests that the FNS-KE exercise may provide a deterrent to bone loss in SCI individuals.

Based on these findings, FNS-induced KE exercise may be most beneficial to recently injured SCI individuals to maintain muscle strength and endurance and retard bone loss. In addition, those SCI who require specific FNS training of the quadriceps in preparation for more strenuous FNS activities such as cycling, standing, or ambulation may also benefit from FNS-KE training.

ACKNOWLEDGEMENTS

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KINEMATIC-EMG FEEDBACK TRAINING AND FES SYSTEM FOR SPINAL CORD INJURED PATIENTS

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Abstract

A Kinematic-EMG Feedback Training and Functional Electrical Stimulation (KEFT/FES) system has been developed to train and assess motor recovery and response to a combined protocol of electrically stimulated exercise in conjunction with a scheme of multi-modal feedback. Commercially available equipment has been augmented with custom computer and stimulation systems to realize a system to provide enhanced treatment and assessment capabilities for stroke and spinal cord injured patients. This system expands upon previous research efforts utilizing electromyographic (EMG) biofeedback or positional biofeedback alone or in conjunction with electrical stimulation to take advantage of the additional performance measurements available with newer commercial equipment.

Introduction

Positional and EMG feedback have been used alone and in combination with electrical stimulation to improve muscle performance in patients with orthopaedic and upper motor neuron disorders in previous studies with significant improvements seen in patient recovery and improvement of motor skills. In a study by Bowman et al [1] hemiplegic wrist patients treated with a positional feedback stimulation system in a 4 week protocol demonstrated a 280% increase in isometric extension torque compared to control subjects who showed no significant increases over the same period of time.

A similar study by Cozean et al [2] tested the efficacy of functional electrical stimulation and EMG biofeedback alone and combined in the treatment of gait dysfunction in patients with hemiplegia after stroke. Patients were divided into four groups and in the control group received no biofeedback or stimulation, received either stimulation or biofeedback alone or in the fourth group received combined therapies. Combined therapy resulted in improvements in both knee and ankle minimum flexion angles during swing phase that were statistically significant compared to any of the three remaining groups. The fourth group also showed increased average length of stride and reduced double stance time compared to the other groups.

The training system described here expands upon the EMG biofeedback or positional signals previously utilized and will allow the evaluation of joint position, velocity, torque, and EMG (and in versions currently being developed, joint effort measured as work or power) in the feedback signal and so elicit the patient's optimal response prior to the onset of electrical stimulation and can accommodate the feedback training needs of each individual patient.

System Description

The training system is comprised of a Loredan Biomedical (Davis, California) LIDO Active Isokinetic Rehabilitation System modified to provide torque, position and velocity analog signals to an external IBM PC/AT computer. The knee, hip, shoulder, elbow and writst joints may be tested with this system.

The IBM PC/AT laboratory computer has been equipped with a Data Translation 12 bit, 16 channel data acquisition system and a custom four channel electrical stimulation system [3]. External to the computer is a stimulation amplifier capable of delivering compensated monophasic stimulation pulses up to 250 mA into 1 KOhm loads and an EMG preamplifier and electrode assembly utilizing a programmable gain instrumentation amplifier from Burr-Brown. Either surface or fine-wire intramuscular electrodes may be used.

A custom four channel programmable gain and offset amplifier with programmable filter functions is used to condition all of the above signals ultimately sampled by the Data Translation system. The stimulation system, data acquisition system and amplifier/filter systems are controlled by a program written in the C programming language which allows complete data collection and analysis and feedback displays for the patient.

Application

In practice, the LIDO system is prepared for use with the desired joint and the laboratory computer system is calibrated to the LIDO system, including gravity compensation of the limb and its transducer arm. Feedback signals from the LIDO system and an EMG amplifier system are combined using therapist selected weighting factors to determine the contribution of each signal in the determination of threshold performance of the patient.

Following the selection of weighting factors is the determination of threshold and target signal levels for each of the non-zero weighted parameters. Resting position, velocity, torque and rectified and integrated EMG signals are sampled by the system, and then target levels are determined so that the system can determine when to augment patient performance with electrical stimulation. Stimulation parameters are independently determined in an associated procedure within the program.

A treatment session starts by signaling the patient to proceed with a message on the video graphics display. Performance threshold is defined when the sum of the weighting factors multiplied by peak position, velocity, torque/moment or rectified/integrated EMG values relative to resting values during a voluntary effort meet or exceed a value of 100. When the patient is able to reach the threshold level of voluntary performance, electrical stimulation is applied to the desired motor groups for a predetermined amount of time. A rest time follows, and then the patient is again requested to repeat the effort. Color video graphics show the status of the patient's voluntary effort based upon the weighting factors applied to the position, velocity, torque and EMG signals sampled by the system in simple terms.

Following the treatment/exercise program, summary statistics are reported in both tabular and plotted formats on both the video display and in hard copy.

Discussion

While studies testing the validity of the system described above are not yet complete, based upon pilot data and previous evidence by other researchers using facets of our system, there is every reason to believe that the system will prove useful in augmenting traditional therapy programs for hemiplegic patients. The additions to the Loredan device could easily be duplicated either by other laboratories and instututions or by the manufacturers of like exercise equipment. Full experimental evaluation of the system will be forthcoming.

Acknowledgements

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P3.4

ELECTRICAL STIMULATION AND SPASTICITY: THE CHALLENGE OF OBJECTIVE DOCUMENTATION

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Abstract

The purpose of this paper is to present a system to document resistance to passive joint motion (RPJM) at velocities up to 230 deg/sec as well as a protocol to show change in RPJM after electrical stimulation (ES). A velocity dependent RPJM (Nm and Nm-deg) has been documented at the knee, hip, shoulder, elbow and wrist in normal subjects (instrumentation induced moments and gravity eliminated). Identification of mechanical and neurological contributions to RPJM awaits the concurrent use of intramuscular electromyography (EMG). Preliminary results in complete paraplegics indicate increased RPJM at slow velocities and a steeper slope of the moment versus velocity relationship when compared to normal. These findings have immediate application to patient evaluation and to the acquisition of neuromuscular data.

Introduction

Documentation of change in spasticity as a result of (ES) mandates a distinction of mechanical, neurological and instrumentational contributions to the resistance to joint motion. Although the "bottom-line" in clinical practice is to document that the patient can accomplish a functional task as a result of reduced interference from involuntary, antagonistic muscle action, it is essential to quantify change in muscle performance in order to establish a rationale for treatment.

Mechanical properties of muscle have been credited with RPJM [1-4,8]. RPJM has been correlated with muscle cross section area [8]. While the extent of reflexive muscle contraction observed during PJM in normal subjects is controversial, EMG activity was shown in spastic patients [1,4,6]. Systems described to date do not permit optimal separation of the mechanical and neurological contributions to RPJM. The purpose of this paper is to present a system to assess RPJM; to report data for healthy subjects and to compare preliminary findings in spastic paraplegics.

Methods

PJM was controlled by an isokinetic multi-joint system (Lido Active, Loredan Biomedical, Davis, CA 95617). The controller was modified to provide four analog signals to an IBM PC/AT computer for angular position, velocity, torque or moment and position. Calibration, gravity compensation (GC), data acquisition and management were carried out by the IBM. Software protocols were modelled after Carter [2]. Continuous passive motion was performed at 60 to 230 deg/sec at the knee, hip, shoulder, elbow and wrist. Surface electrodes over the quadriceps collected EMG data in knee PJM (50 uV/div, 10msec/div)(5200A, Cadwell Laboratories, Kennewick, WA, 99336). Ten joint cycles (oscillations) were done at each test velocity and work (Nm-deg, trapezoidal rule, 100Hz) was plotted against time and position. Comparisons were made between cycles to assess the differences due to moment arm acceleration. Calculations were performed for the full joint excursion and for selected mid-range segments. BMDP was used for descriptive analysis and repeated measures ANOVA. All moment data were GC and corrected for moment arm values (system empty and GC). Differences among velocities were identified by paired-t tests (Bonferonni).

Results

A velocity dependent RPJM was demonstrated in the five joints tested in 15 normal adults (20-25 years). Although significant differences were present among all four velocities (60,90,120 and 18C deg/sec) at the hip ($p<.01$), changes in response due to velocity were best appreciated in all joints when slow and fast velocities (ie a difference of 140 deg/sec) were compared. Work (Nm-deg) was a more revealing variable than peak moment (Nm). No EMG activity was recorded during knee PJM (60 to 230 deg/sec). The magnitude of moments generated at each joint was consistent with the associated muscle mass, however, there was no consistent relationship between the estimated mass of individual muscle groups [7] (ie flexors vs extensors) and the moments produced. Preliminary findings in complete paraplegics indicate a marked velocity dependent response to PJM at the hip and knee. The patients (21-25 years old) had clinically complete lesions with no evidence of denervation (EMG/nerve studies) nor continuity of sensory/motor cord pathways (central motor evoked/ somatosensory evoked potentials). RPJM was greater throughout the range (Fig 1) and the slope of the work vs velocity relationship was steeper for the spastic patient (Fig 2). Moment vs position plots revealed a cyclical resistance commensurate with muscle clonus [1].

Discussion

This methodology provides for clinical documentation of patient status and for laboratory data acquisition. Minimal modification of a commercially available device permits the assessment of biological resistance to PJM, with instrumentation error and the effect of gravity eliminated. Moment and work values may be derived satisfactorily from mid-range data gathered in cycles 3-10 for normal subjects. These velocity dependent RPJM for the hip, knee, shoulder, elbow, and wrist are the first examples of normative data with this isokinetic protocol. The lack of correlation between estimated muscle mass [7] and the moments generated during stretch is also new information. Identification of mechanical versus neurological contributions to the biological resistance to PJM awaits further study with intramuscular EMG. The pitfalls of surface electrodes, previously documented by Perry, et al. [3], were evident during the pre-test protocol in this study when EMG from the knee flexors was sensed by electrodes placed over the quadriceps.

Differences between SCI and normal are marked. Change in the spastic patient will be best appreciated when the entire joint excursion is analyzed (after removal of forces generated by the instrumentation). Cycles 1 and 2 should be included in the analysis when RPJM is greater during the initial cycles. These findings have immediate application to the documentation of change in RPJM as a result of biological variability or as a result of intervention, such as ES [6].

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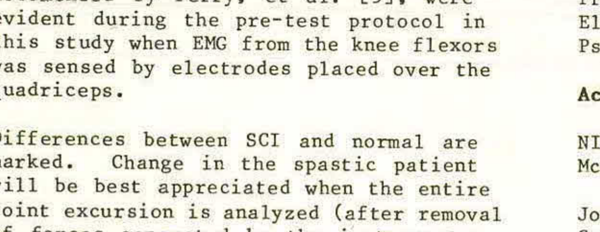

Fig 1-a: Normal Subject

Fig 1-b: Paraplegic

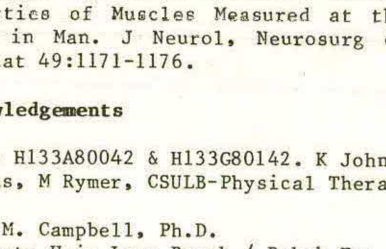

Fig 2: Work vs Velocity for Hip Flexion and Extension

FATIGUE OF ELECTRICALLY STIMULATED MUSCLE IN PARAPLEGIC SUBJECTS

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ABSTRACT

Muscle fatigue due to electrical stimulation was tested in paraplegic individuals. Stimulation of quadriceps muscles was cyclic with various ON/OFF times. Data shows the strongest correlation between OFF time and fatigue and no correlation between ON time and fatigue in the ON/OFF combinations tested. Fatigue was also found to increase with increased stimulation frequency and increased resistance to isokinetic movement.

INTRODUCTION

Functional electrical stimulation (FES) has been used to provide paraplegic subjects with simple mobility. The control of the muscle stimulation has been for the most part open loop and few attempts were made at closed-loop control. The basic problem with stimulation is that the less fatigue resistant fast twitch fibers are stimulated first. Therefore, to achieve reasonable torques at the joints during prolonged walking we must rely mostly on fatigue resistant slow twitch fibers which produce lower forces. Further inefficiency of FES is compounded by the lack of proper timing and control of muscle force during walking. Using excessive stimulation during walking causes both cardiovascular and muscle fatigue. Usually, at the beginning of a walk the subject has good forward momentum and the movements during the swing phase of the gait are exaggerated for the first 200 ft. Thereafter, the subject slowly loses the forward momentum and becomes unstable at the hip. The swing leg starts to cross over often hitting the stance leg and the toe begins to drag. Because open loop control uses preprogrammed patterns of stimulation it is easy to imagine how the imbalance could occur when various muscles are fatiguing at different rates. This study was designed to help understand how various factors including frequency of stimulation, antagonist activity, duty cycle, OFF time and ON time affect the fatigue.

METHODS

The subjects included in this study were participants in a program to restore walking in paralyzed individuals. They were all paraplegics with complete absence of motor function and sensation below their level (T5-T8) of injury. They were implanted with percutaneous intramuscular wire electrodes in all major muscles controlling the trunk, hip, knee and ankle. They used microprocessor controlled stimulators for home exercises and laboratory walking sessions at least three times a week for one half hour.

The muscles included in this fatigue study were vastus lateralis, vastus intermedius and vastus medialis. Cyclic isokinetic tests at the resistance of 60 deg/sec from 0 to 90 degrees of knee flexion were done on Cybex, a commercially available dynamometer. All combinations of stimulation with 1,2 and 3 seconds ON and 1,2 and 3 seconds OFF were tested. At 1 sec ON and 3 sec OFF the effects of stimulation frequency and resistance to movement were tested. Data were collected using a portable microprocessor controlled data collector where torque and angle data were synchronized with stimulation. Data were transferred to the MicroVAX minicomputer for plotting and data analysis. The amount of fatigue was defined as percent difference between the maximum and steady state torque measured after 60 minutes test.

RESULTS

Average day to day repeatability of the maximum torque at the same stimulation parameters in a conditioned muscle was within 6%. The data shows a strong inverse relation between OFF time and fatigue (Fig. 1). Less correlation was found between duty cycle and

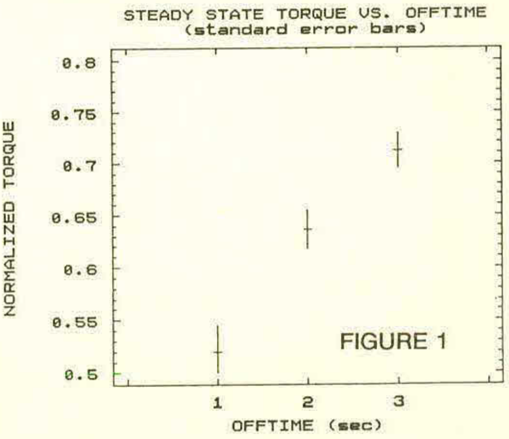

FIGURE 1

fatigue (Fig. 2) and no correlation between ON time and fatigue (Fig. 3) in the ON/OFF combinations tested. For example, during cyclic stimulation with 1 sec ON/1 sec OFF and 3 sec ON/3 sec OFF, which have the same duty cycle of .5 (DUTY CYCLE=ON TIME/ON TIME+OFF TIME), muscle fatigued much quicker at the lower rest time. The muscle also fatigued much faster during cyclic stimulation when the resistance to leg movement was increased by reducing test speed from 90 deg/sec to 30 deg/sec. Also reducing the frequency at the same duty cycle and resistance reduced the fatigue.

DISCUSSION

The results of cyclic fatigue tests suggest the amount of rest time between contractions, the amount of resistance offered by antagonists and the frequency of stimulation all have an effect on the rate of muscle fatigue. There is of course a trade off on each of these. Using lower stimulation frequency will reduce the initial torque and the steady state torque may not be sufficient to produce a desired function. Reducing activity of antagonists will reduce fatigue, but at the expense of joint stiffness. Increasing the rest time may be the most difficult to achieve in a preprogrammed open loop stimulation. If there is redundancy in muscle action at various joints, that could be used to increase the rest period of muscles. Use of closed loop control of stimulation could reduce fatigue by optimizing rest time, controlling the stiffness of joints and regulation of stimulation frequency; but such controllers would have to deal with potentiation, shifts in recruitment curves, rise time and relaxation effects of fatigue among others.

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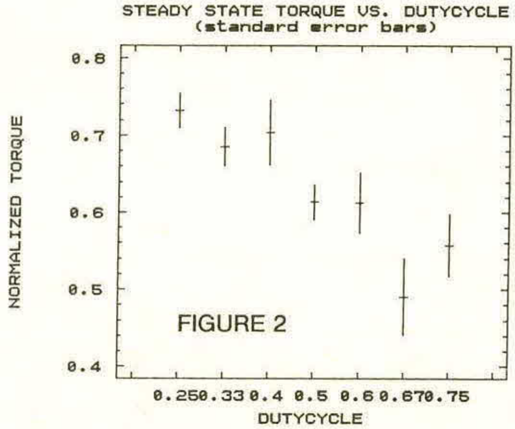

FIGURE 2

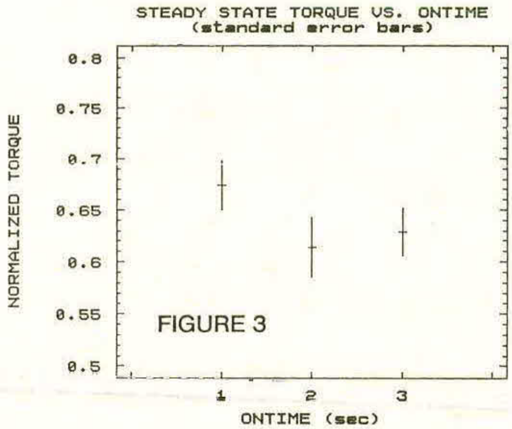

FIGURE 3

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A DOUBLE HELIX ELECTRODE FOR FUNCTIONAL ELECTRICAL STIMULATION

P3.6

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ABSTRACT

An electrode, designed to be implanted without a surgical incision, has been developed for skeletal muscle stimulation. Stainless steel, Teflon insulated wire was formed into a double helix configuration for stress relief during muscle contractions. The electrode tip was augmented with stainless steel barbs to increase anchoring strength. Implantation was achieved by mounting the electrode on a 26-gage needle and inserting it through a 15-gage needle to the motor point. The lead was then passed subcutaneously, with a 19-gage passing tube, to a preferred exit site. Over 220 of these electrodes have been implanted (with an average age of 8 months, longest implanted 16 months) over a 16-month period in human subjects. Seventy percent (157) are still functional.

INTRODUCTION

Functional electrical stimulation (4) can be achieved by applying an electric field near a motor neuron in a controlled manner, thus effecting external control over a motor unit. To provide repeatable, selective muscle stimulation, the electrode must be placed close to a target nerve (usually at the motor point) in the target muscle (2). This environment is very harsh compared to other locations where electrodes have been used traditionally (brain, skin surface, heart). The electrode lead passes through many layers of tissue which are constantly moving relative to each other as the stimulated muscle is continually contracting and expanding. This requires a unique electrode design.

ELECTRODE DESIGN

The design criteria for this electrode were: 1) the electrode materials must be biocompatable **in vivo,** 2) the electrode must not corrode or cause tissue damage (3) during stimulation, 3) it must be possible to implant this electrode without a surgical incision, 4) the implantation procedure must be easy and quick (within 15 minutes once the implant site is determined), 5) the electrode must be implantable with great accuracy (within several mm), 6) after implantation the electrode must not move relative to the motor axons being stimulated and 7) the lead must not break due to repeated movements of the implanted limbs (1).

MATERIALS

Lead wire: Ten-stranded (0.048 mm strand diam, AWG 40 gage) 316LVM stainless steel wire insulated with extruded FEP teflon, approximately 75 mm thick, (California Fine Wire Co.) is used for the conductor. The diameter of the wire cable with insulation is 0.28 mm.
Lead core: Polypropolene suture material 5-0 size (0.15 mm diameter) (Ethicon Inc., trade name Prolene) is used for the lead core.
Anchoring barbs: The anchoring barbs are fabricated from 0.1 mm diameter 316LVM stainless steel wire.

These materials were chosen because of their good biocompatability, toughness, strength and durability **in vivo.** In addition, stainless steel has the property of relatively low electrical resistance and high surface capacitance so current can easily be passed from the wire to the body fluids.

FABRICATION

The electrode is constructed by deinsulating 7.62 cm of wire from the (distal) end of the 10 stranded cable. The length of wire is wound onto a 5-0 polyproprolene suture arbor and is then removed from the winding machine leaving the suture inside the coil. Nine centimeters of the distal portion of the lead are wound around a 0.45 mm stainless steel mandril to form a 3 cm double-wound section. Twelve barbs are created by tying 6 pieces of 316 LVM stainless steel wire onto the electrode tip. The end of the polypropolene core is bent over and formed into a .5 mm hook. The electrode is mounted on a 26 gage needle with a 17-gage tamper and 15 gage barrel for implantation (figure 1).

ELECTRODE DESCRIPTION

The double helix design provides an electrode that is uniquely adapted for use in stimulation of skeletal muscle. The ability to implant these electrodes accurately without surgical incision, and still have the mechanical flexibility, is very important. A paraplegic subject may need to have more than 50 implanted for full functional control. The amount of tissue scarring involved would be unacceptable if incisions had to be made. The shape and size of this electrode allow it to be inserted to the implant site through a 15-gage needle with minimal tissue damage. The double helix configuration of this electrode has a very low spring constant which provides stress relief for the electrode tip and lead. This stress relief is important because the relative movement of tissue planes through which the lead is routed would cause lead breakage or movement of the electrode tip. The design of this electrode theoretically allows 1) an electrode with a 3 cm double helix section to displace approximately 6 cm at the electrode tip before electrode movement or 2) the tissue surrounding the electrode can stretch approximately 200% before the electrode becomes dislodged. The anchoring barbs at the electrode tip have been spaced out all along the deinsulated section. By spacing the barbs, we distribute the loads on the electrode and the muscle tissue during muscle contraction. By distributing the load, we decrease the likelihood of electrode material or muscle tissue failure and electrode movement.

IMPLANT PROCEDURE

Implantation is achieved by mounting the electrode on to a 26 gage needle and inserting it through a 15 gage needle to the motor point. The lead is then passed subcutaneously, with a 19 gage passing tube, to a preferred exit site.

PERFORMANCE

Over 220 of these electrodes (as of 12/89) have been implanted (with an average age of 8 months, longest implanted 16 months) in paralyzed human subjects. One hundred and fifty seven (71%) of these electrodes are currently active. Forty-two have been removed because of incorrect muscle response (assumed electrode movement or incorrect placement), 13 have been removed because of high impedance (assumed breakage), 6 have been removed because they caused the patients intolerable pain, 1 has been removed because of an infection, and 2 have been removed for other reasons (patient left program, electrode accidentally pulled).

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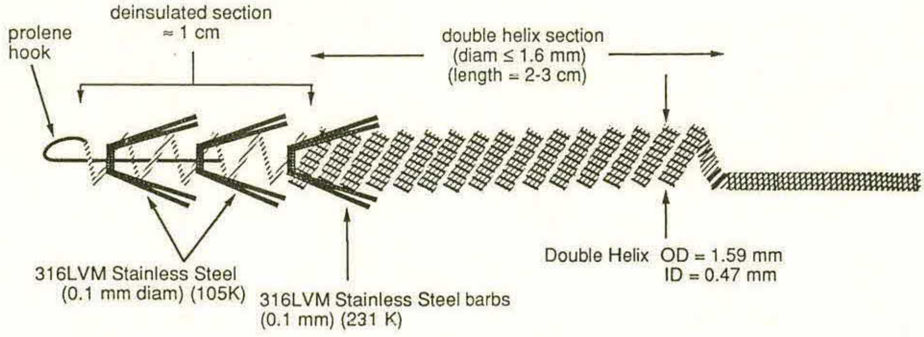
Figure 1: Double Helix Electrode



Design of a Locking Knee Joint for Use With Hybrid FES Systems

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Abstract

A locking knee joint has been designed for use on a lightweight knee-ankle-foot orthosis for use with a hybrid FES system. The joint can be locked and unlocked in any position, and can hold 1300 inch pounds of torque around the medial-lateral axis with a brake actuator force of less than three pounds. A simple band brake design is used with a neoprene drum surface and a stainless steel band. The locking mechanism is normally locked for a fail-safe design. A brace with the knee joint will allow a more physiologically correct gait.

Introduction

Practical approaches to locomotion restoration have not changed a great deal over several decades. Wheelchairs and braces have remained the only reliable choices for paraplegic mobility. Functional Electrical Stimulation (FES) systems have shown promise in the laboratory, but will not be, in the near future, reliable enough to use without braces.

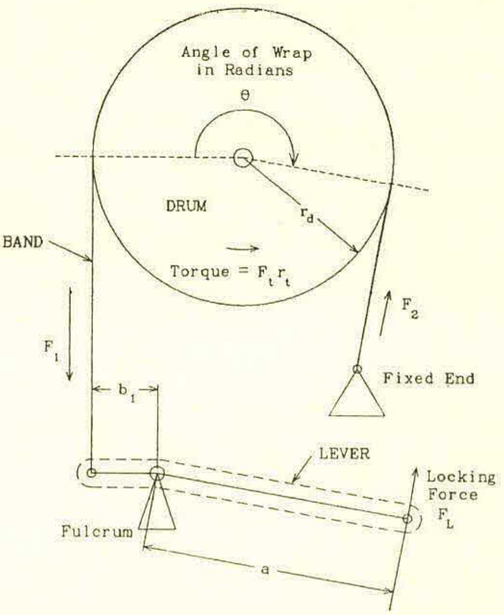
Several FES research groups have implemented some orthotic brace (1-4). The combination of FES and a brace eliminates some of the disadvantages of either method by itself. Such hybrid systems use knee-ankle braces and between 2 and 5 channels of stimulation bilaterally including the quadriceps muscle (5). Early research has shown promise in the laboratory, but due to size, weight of support electronics, and the precarious positioning of the locked knee patient during transition to and from a wheelchair, the hybrid system has not been proven practical outside the laboratory. Braces for use without FES keep the legs straight and cause energy intensive non-physiological limb trajectories (6). "Brakes (at the knee joint) can also be used effectively in purely dissipative activities such as a controlled transition to sitting" (6). Still needed is a lightweight knee-ankle orthotic brace that will lock and unlock in any position, rapidly enough to allow reciprocating gait. This newly designed knee joint is a significant step towards this goal.

Design

Ideally the knee joint would lock and unlock, by computer control, in any position, with or without torque applied to the joint, in less than 100 milliseconds. The locking joint should not only achieve this repeatedly, one lock-unlock cycle per step, but weigh less than two pounds and be smaller than four inches square and one inch thick. This may not seem too difficult until the amount of torque seen at the knee is determined. According to two sources (7,8) maximal torques experienced at the knee with a brace are approximately 1300 inch-pounds which is equivalent to a force of over 100 pounds at a distance of one foot. Providing a locking device to hold this torque is first priority for the knee joint design. Second is that the locking device be fail-safe, followed by cost, size, and weight minimization.

A simple band brake design was chosen for its great mechanical advantage characteristics (figure 1). This mechanical advantage increases exponentially as the angle of wrap of the band or the coefficient of friction increases. For example, if the angle of wrap (theta) is five radians and the friction coefficient (μ) is 0.5, then a force one twelfth of F2 , F1 exists when the brake is locked. The brake drum is simply a 40 tooth aluminum timing pulley covered with a 40 tooth timing belt made of neoprene. The band material is stainless steel. This combination of materials has a μ of about 0.7 when the normal pressure is below 1000 pounds per square inch. However, it was discovered that when higher normal pressures are applied, as in earlier models of the

Simple Band Brake



$$F_L = \frac{a \text{ Torque}}{b_I \ r_d} e^{\mu \theta}$$

Figure 1. Schematic diagram of a simple band brake. The equation for the locking force is shown.

brake design, the μ drops significantly. When there is such a drop in the friction coefficient, there is an exponential drop in mechanical advantage and the brake slips. Doubling the width of the drum to 0.375 inches brought the pressure between the band and the drum below the 1000 psi limit for torques below 1300 inch-pounds. The current design of the knee joint (figure 2) uses a compression spring to keep the joint in the locked position. To release the brake, the cable to the left of the spring is pulled by an actuator.

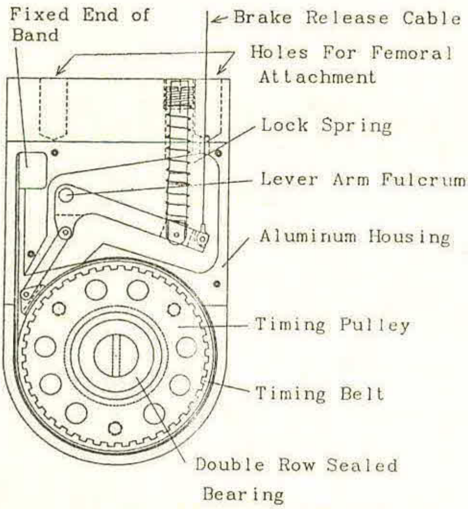


Figure 2. Knee joint assembly with lever arm cover and tibial attachment removed.

Results and Conclusions

In figure 3, force applied to the lever 1.6 inches from the lever fulcrum and displacement from the unlocked position are plotted against the torque applied to the drum. The non-linear shape of the plots is expected due to the changing effective lever arm in the linkage to the band. As the lever tightens the band, the short arm of the lever shortens, thus increasing the band tightening force with little increase in the force of displacement at the long end of the lever. With this configuration, the required 1300 in-lbs. of torque can be held with less than 3 lbs. force. Design of an actuator is currently being accomplished using fractional-horsepower DC motors that will allow a FES computer to lock and unlock the knee.

Acknowledgements

Funding for research was provided by The Veterans Administration Rehabilitation Research and Development grant number B486-DZ2.

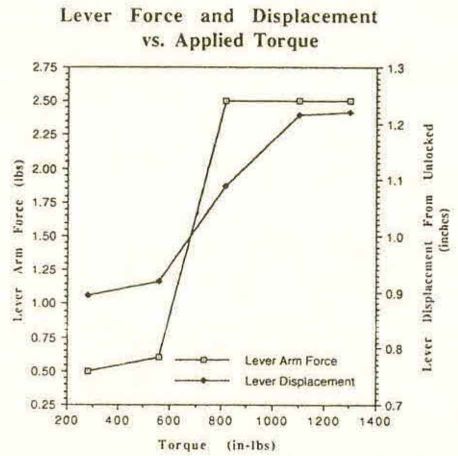


Figure 3. Plot of knee joint locking characteristics.

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FUNCTIONAL ASSESSMENT OF QUADRIPLEGIC PATIENTS USING A HAND NEUROPROSTHESIS

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INTRODUCTION

Over the past ten years, C5 and C6 quadriplegic patients have been implemented with a portable hand neuroprosthesis that provides unilateral control of hand grasp using functional neuromuscular stimulation (FNS). The neuroprosthesis synthesizes both lateral grasp (key-grip) and palmar grasp (three-finger pinch) by electrically stimulating the paralyzed muscles of one hand via percutaneous electrodes. The stimulation is controlled by movement of the contralateral shoulder using an external shoulder angle transducer and associated electronics.

The C5 and C6 quadriplegic patients retain enough voluntary control of their shoulder and elbow flexor muscles to position their hand for functional activities. The C6 quadriplegic patients also have voluntary control of their radial wrist extensors, which provides them with tenodesis grasp. Both C5 and C6 quadriplegic patients typically depend on attendant assistance, wrist-hand orthoses and adaptive equipment or modified objects to perform activities of daily living. To determine whether the hand neuroprosthesis can reduce such dependence, a retrospective study was conducted to compare performance in ADL with and without the neuroprosthesis across all the patients who have used the device.

METHODS

Twenty two patients participated in the study, four female and eight male. Fifteen patients had a C5 spinal cord injury (SCI) and seven a C6 SCI. Typically, the neuroprosthesis was implemented in the stronger arm, the contralateral shoulder was used to control the device, and the contralateral arm was used to assist in performing tasks. However, because of poor balance or a C4 SCI on one side, seven patients performed activities unilaterally. Although all the current users of the hand neuroprosthesis are provided with a lateral grasp and a palmar grasp, seven former users only had a lateral grasp. This grasp is not appropriate for two of the activities in the study: drinking from a glass and answering a telephone.

Through telephone interviews, the patients were asked if they had performed ten activities of daily living, how they had performed the activities, and whether they had used a wrist-hand orthosis or universal cuff. The performance of the activities both with FNS and without FNS was determined for the time period that the patient actually used the hand neuroprosthesis. The interviews were tape recorded and were about 30 minutes long. Patient files and videotapes were also reviewed to corroborate the telephone interviews.

The ten activities of daily living used in this study were selected by reviewing upper-extremity functional tests, ADL indices and SCI treatment manuals. The ten activities are: eating with a fork, drinking from a glass, drinking from a mug, eating finger foods, brushing teeth, applying toothpaste on a tooth brush, answering a telephone, writing, handling a computer diskette, and holding a book with one hand.

Without the hand neuroprosthesis, patients were allowed to use a universal cuff or a passive wrist-hand orthosis with a utensil pocket. No further adaptive equipment was permitted.

The performance of each activity was scored as a "success" if it was completed successfully, as a "failure" if the activity was attempted but never completed, and as "not tested" if the activity was never attempted or if the patient did not have the appropriate grasp to perform the activity. The final score of each task, both with and without FNS, was defined as the most successful score obtained from the interview, patient files or videotapes.

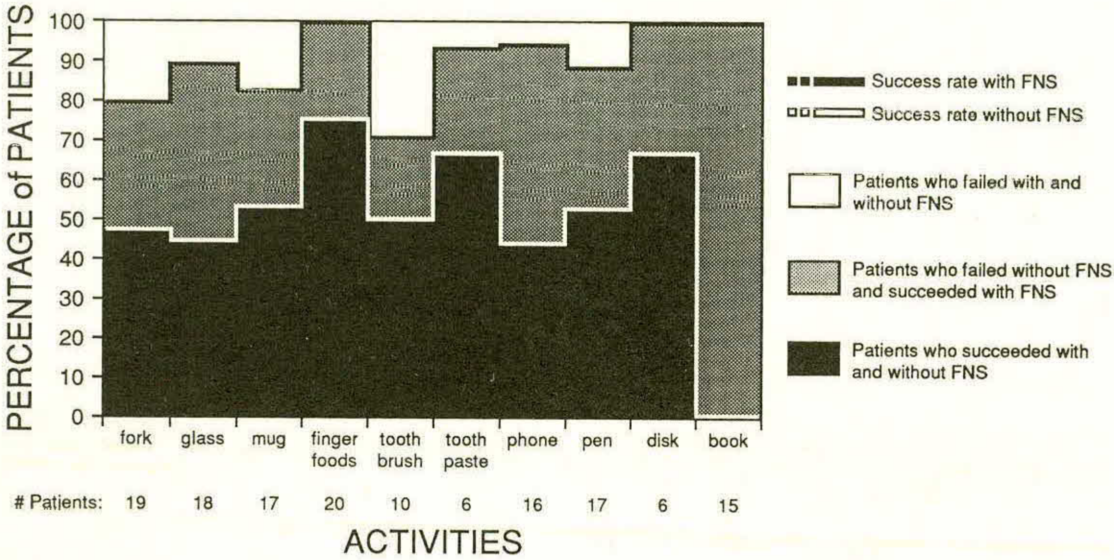
The reliability of patient recollection was assessed by reviewing patient files and videotapes. Forty-six percent of the analyzed data could be validated by videotapes and patient files. Of these, 87% were confirmed and 13% were overruled They were overruled because a patient did not remember attempting a task, or the patient did not recall performing the task successfully, although the videotapes or patient files showed otherwise. Overall the results of the direct comparison show that patients were able to recall past performance with reasonable accuracy.

The data were analyzed across patients for each activity. To avoid misleading comparisons, only patients who attempted the activity both with and without the hand neuroprosthesis were included in the results for a particular activity.

RESULTS

The results are summarized in Fig. 1. The abscissa lists the activities and the ordinate is the percentage of patients who succeeded or failed the activity with and without the neuroprosthesis, out of the patients that were tested for each activity. The actual number who attempted the activity both with and without the neuroprosthesis is listed below each activity. The success rate for each activity is defined as the percentage of successful patients out of all the patients who attempted the activity. In Fig. 1, the heavy black line is the success rate with the hand neuroprosthesis, and the white line is the success rate without the hand neuroprosthesis. The success rate with the hand neuroprosthesis was greater than without for every activity, and was 89% over all the activities combined. The success rate without the hand neuroprosthesis was 49% for the combined activities.

With the exception of two activities in one patient, performance was not impaired when the hand neuroprosthesis was used. That is, if an activity was completed without FNS it also was completed with FNS. Likewise, failure with FNS was accompanied by failure without FNS. The two exceptions are in eating with a fork and brushing teeth. One C5 patient was unable to complete these activities with his hand neuroprosthesis but could complete them without. Apart from these two activities for one patient, each patient who was tested belonged to one of three performance categories as shown in Fig. 1: 1. The proportion of patients who were successful both with and without the hand neuroprosthesis (black area). 2. The proportion of patients who were successful with the hand neuroprosthesis, but failed without (gray area). 3. The proportion of patients who failed both with and without the hand neuroprosthesis (white area).



The performance of the patients in the first category (black area) could not "improve" with the hand neuroprosthesis, because these patients were already successful without the hand neuroprosthesis. This definition of improvement is conservative, though, since it only considers the completion of the activity, and not other measures such as quality or speed.

The proportion of patients in the second category (gray area) is equal to the fraction of patients who were successful with FNS but failed without FNS, out of the total number of patients tested. This has been termed "Total Improvement" (TI). Hence:

$$TI = \frac{\text{Successes with FNS - Successes without FNS}}{\text{Patients Tested}}$$

The "Optimal Improvement" (OI) is the fraction of patients who were successful with FNS out of the number of patients who failed without FNS. Hence:

$$OI = \frac{\text{Successes with FNS - Successes without FNS}}{\text{Patients Tested - Successes without FNS}}$$

In other words, the optimal improvement is the fraction of patients who *did* improve out of the patients who *could* improve. This can be observed by the gray and white areas alone.

Patient performance was also compared between the fifteen C5 and the seven C6 quadriplegic patients in the study. For eight activities, the total improvement was greater for the C5 quadriplegic patients than for the C6 patients. The total improvement for the combined activities was 46% in the C5 group, and 30% in the C6 group.

DISCUSSION & CONCLUSIONS

The results show that more patients were successful with the hand neuroprosthesis than without the neuroprosthesis for each activity. Of the 144 responses that could be analyzed, 128 indicated successful completion with the neuroprosthesis for a success rate of 89%; compared to only 70 successes without the neuroprosthesis, for a success rate of 49%. The total improvement, defined as the fraction of patients who were successful with FNS but failed without FNS, out of the total number of patients who either succeeded or failed without FNS, was 40% across all tasks. The optimal improvement, defined as the fraction of patients who were successful with FNS out of the number of patients who failed without FNS, was 70%. An assistive device should yield a high optimal improvement, so that patients who are able to improve actually improve with the device. For the tasks in this study, the optimal improvement varied from 40% to 100% for individual tasks, and was 78% across all tasks. These measures of improvement are conservative estimates of the benefits provided by the neuroprosthesis since they do not include changes in performance characteristics such as quality, level of independence, preference, speed, or assess integration across activities.

The results suggest that the hand neuroprosthesis is a useful device for C5 and C6 quadriplegics. Furthermore, the total improvement for the combined activities was 46% in the C5 patients and 30% in the C6 patients, which suggests that C5 patients will realize greater benefits from the hand neuroprosthesis than C6 patients. The C6 patients, who have tenodesis hand function, are more independent in the performance of ADL.

ACKNOWLEDGE

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EFFECT OF DC ELECTRICAL STIMULATION ON PRESSURE SORE HEALING IN PIGS

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ABSTRACT

A recently developed animal model for stage 3 pressure ulcers was used to study the influence of DC electrical stimulation on wound healing. Two groups of animals were used. One group was treated daily using DC stimulation while the second non stimulated group served as controls. Changes in wound size (area and volume) and tissue perfusion were measured and recorded as dependent variables. The exponential wound healing model of Vodovnik and Stefanovska was used to calculate healing time constants(1). Results indicated reduced healing time constants as measured using area and volume for the DC stimulated animals versus controls. Transcutaneous oxygen measurements showed no difference between the stimulated and non-stimulated groups.

INTRODUCTION

A number of existing studies(2) indicate that local surface electrical stimulation may be effective in the promotion of ischemic tissue healing and the prevention of pressure sores. Both direct and pulsating currents have been effective, suggesting different mechanisms for the interaction between tissue healing and electrical energy. In this study, the effect of DC electrical stimulation on wound healing was observed by the parameters of wound area, wound volume and tissue perfusion. A published pressure sore model consisting of the application of 600mmHg for 6 or more hours was intended for use in this study but the model did not produce stage 3 pressure sores. The thickness and strength of the pig dermis was found to be highly resistant to loading and the unchanged vitality of the tissues resulted in rapid healing. For this reason a newly designed pressure applicator was developed. A protocol for generating consistent pressure sores in mini-pigs was developed and used in this investigation.

MATERIALS AND METHODS

Ten pigs were used in this study. The first step in the protocol was denervation surgery. A skin incision was made in the midline of the back from L1 to S1 level. The partial removal of the laminae was done from L2 to L7 to visualize the dura and nerve roots. The nerve roots of the right side were cut and the wound closed. Post operatively, aspirin for pain relief and ampicillin for infection control were given for seven days. A fiber-glass cast was applied on the right foot to prevent the pig from self injury of the insensitive foot.

Pressure sore formation followed seven days after denervation. The applicator consisted of a modified percutaneous cancellous bone screw with a 2.5 cm threaded end extending outside the skin. The cancellous end was inserted into the greater trochanter of the femur perpendicular to the skin surface through a small skin incision. A 3cm diameter plastic indentor washer was compressed against the skin by a calibrated spring. Spring compression was maintained by a lock nut and washer. A constant pressure of 800mmHg was maintained continuously for one to three days. Each day the tissues were inspected, cleansed and the pressure reapplied until the desired stage of ulcer was reached. Debridement of necrotic material to viable bleeding tissues completed the development of the pressure sore. The subsequent daily treatment included change of dressing, cleansing with saline, loose packing with 0.25% acetic acid soaked gauze and administration of oral antibiotic.

The treated group (5 pigs) received direct current stimulation with electrodes applied on the healthy skin distal and proximal to the wound about 3 cm away from the edge of the wound. The cathode was always placed distal to the wound. The stimulus amplitude was maintained up to 1 mA with current density in the range of 10 to 50 $\mu A/cm^2$, depending on the size of the wound. Current was applied for 2 hours daily and began with the first day following debridement.

Wound area and volume were measured several times during the course of the experiment. Areas were obtained from photographs of the wound using a disk of known area for calibration. Wound volume was calculated by filling the wound with a measured amount of saline to the level of the intact skin surface.

An indication of tissue perfusion was obtained through the measurement of transcutaneous partial pressure of oxygen using a Radiometer TCMI. The electrode outputs were calibrated in room air for 152 mmHg oxygen partial pressure and outputs were recorded. Oxygen partial pressure was measured over the shoulder musculature for control data and near the trochanter of the hind leg for experimental observations. Data was tabulated at 15 and 20 minutes from the completion of electrode application. This allowed heating of the tissue to the appropriate temperature and a steady state of oxygen diffusion.

RESULTS

The data in Table 1 illustrates the success in generating highly reproducible and uniform stage 3 pressure sores.

Table 1. Results of Pressure Sore Generation

	Control n=5	Stimulated n=5
Body weight (kg)	15.6 ± 4.1	16.6 ± 4.3
Initial wound area (mm^2)	1075 ± 295	997 ± 375
Initial wound volume (ml)	12.2 ± 2.5	10.2 ± 3.3

The data in Table 2 indicates the time constants obtained when fitting the measured wound areas and volumes to an equation of exponential form.

Table 2. Healing Time Constants from Area and Volume Measurements

	Control	Stimulated	
Area T (days)	13.4 ± 8.5	9.5 ± 3.4	n=5
Volume T (days)	6.1 ± 3.2	5.3 ± 2.5	n=4

The values shown in Table 3 are the grouped average mean and standard deviations for $TCPO_2$ taken at the shoulder and trochanter locations for both stimulated and non-stimulated animals.

Table 3. Transcutaneous Partial Pressure of Oxygen (mmHg)

	Control n=5	Stimulated n=5
Shoulder	57.8 ± 7.4	55.8 ± 6.0
Trochanter	48.3 ± 10.6	45.3 ± 15.8

The data shows no significant difference in $TCPO_2$ for the stimulated and non-stimulated groups.

CONCLUSIONS

1. A new reliable animal model for pressure sore generation has been developed and tested for the study of the effect of FES on tissue physiology.
2. Circuitry has been developed and tested for direct current stimulation of the experimental animals.
3. Time constants for the exponential model of wound healing with DC stimulation was calculated to be 9.5 ± 3.4 days for wound area as compared to 13.4 ± 8.5 for the non-stimulated control wound area. A reduced healing time for the stimulated group is observed, however, more experiments are underway to increase the statistical significance of the data.

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ACCURATE SMALL-SIGNAL CHARACTERIZATION OF MICROELECTRODES

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ABSTRACT

A technique is presented to rapidly and accurately measure the electrical properties of thin-film microelectrodes such as those used for neural prostheses. This technique is based on the principle that once the current density range is determined over which the microelectrodes are linear, impedance spectroscopy can be carried out using swept frequency, constant voltage amplitude sinusoids. This is done using off-the-shelf test equipment which is programmed to carry out the mathematical computations required to null out the effects of electrical parasitic components, resulting in accurate, repeatable measurements of the impedance and phase spectra of the microelectrodes. Typical results for the thin-film iridium devices used by this group are presented.

INTRODUCTION

The method by which microelectrodes are most often electrically characterized is by the measurement of their impedance. The impedance of a microelectrode is a function of both physical characteristics and operational factors. These determinants of impedance include the actual surface area of the microelectrode, the material(s) from which it is fabricated, the surface chemistry of the microelectrode interface, the overall chemical environment in which it is placed, the frequency or frequencies of operation, the current density at the interface, parasitic electrical contributions of the substrate and interconnections, the operating temperature and other factors.

In practice, most of the determinants of microelectrode impedance are beyond the control of the researcher once the device is fabricated and in use. For neuroscience applications, the environment in which these devices are placed is within a mass of neural tissue either in a living organism or in a cell culture chamber. This fixes virtually all of the variables with the exception of frequency and current density.

For recording applications, the object is to obtain action potential signals using a stable, biocompatible transducer with the highest possible spatial resolution and the lowest possible noise. Small, low-impedance microelectrodes are required to meet these goals since the spatial resolution is determined by the physical size of the microelectrode and the impedance of the microelectrode largely determines the Johnson (thermal) noise (and hence the signal-to-noise ratio).

For stimulation applications, one wishes to stimulate neurons using a stable, biocompatible transducer with high spatial selectivity and low impedance. In this case, the selectivity is a function of the current distribution that results in the neural tissue during stimulation. The desire for low impedance here stems not from a drive to increase the signal-to-noise ratio, but rather to increase the maximum stimulation current which can be safely (without degradation of the microelectrode) be passed into the neural tissue. Since electrode degradation is mediated by voltage-dependent chemical processes, a lower impedance naturally facilitates the delivery of the required current with lower voltage excursions of the microelectrode.

Accurate measurements of the small-signal electrical characteristics of microelectrodes are useful when comparing the properties of different microelectrode materials and geometries, determining the effects of surface modifications and measuring the stability of microelectrodes over time. While small-signal techniques do not convey enough information to determine the operational characteristics of microelectrodes used for stimulation, these methods can be used to assess degradation of the microelectrodes as they are used.

MATERIALS & METHODS

As discussed in a previous publication [1], fabrication techniques suitable for chronically implantable microelectronic neural interfaces are under development by this group. We have been characterizing these thin-film iridium microelectrode arrays using constant voltage amplitude, time-domain impedance spectroscopy. The test setup used for these measurements is shown in Figure 1 below. A Hewlett-Packard model 3577A network analyzer (Hewlett-Packard Co., Palo Alto, CA) in conjunction with a shielded test chamber and simple circuitry allows the impedance and phase characteristics of the device under test to be accurately determined. The sinusoidal output of the network analyzer is used to directly drive the microelectrode and is fed back into the reference input of the network analyzer to enhance the accuracy of the measurements. The microelectrode array and platinum counter-electrode are immersed in a petri dish containing normal saline (0.9%). A large counter-electrode is used so that the impedance of the microelectrode under test completely dominates the impedance measurements (relative to the impedances of the bulk saline solution and the counter-electrode, which are very small).

The undesired coupling parasitics in parallel with the microelectrode impedance and the short-circuit impedance of the test setup in series are measured and stored. Their effects are removed from the final impedance values in real-time by utilizing the complex-number floating-point computational capabilities of the network analyzer. The corrected impedance spectra can then be downloaded to the host computer, an Macintosh II™ (Apple Computer Inc, Cupertino, CA) over the IEEE-488 bus for further analysis and/or storage.

To ensure the accuracy of the small-signal characterization, the region of linear operation of the microelectrodes must be determined. This is done by completing impedance measurements for the frequency range of interest (here 10 Hz to 100KHz) at various amplitudes of applied sinusoidal voltage. By computing the applied current density at each data point, the data can be rearranged to show impedance (or phase) versus current density as shown in Figure 2 below. As can be seen, this microelectrode's nonlinear behavior can be avoided if the amplitude of the constant voltage sinusoid applied is kept below 100 mV peak-to-peak.

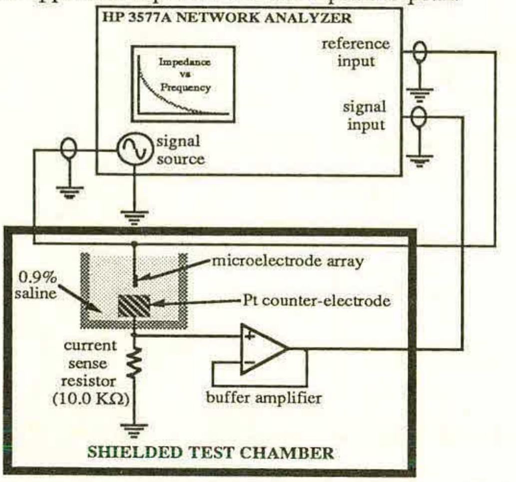

Figure 1: Block diagram of the constant voltage amplitude impedance spectroscopy test setup.

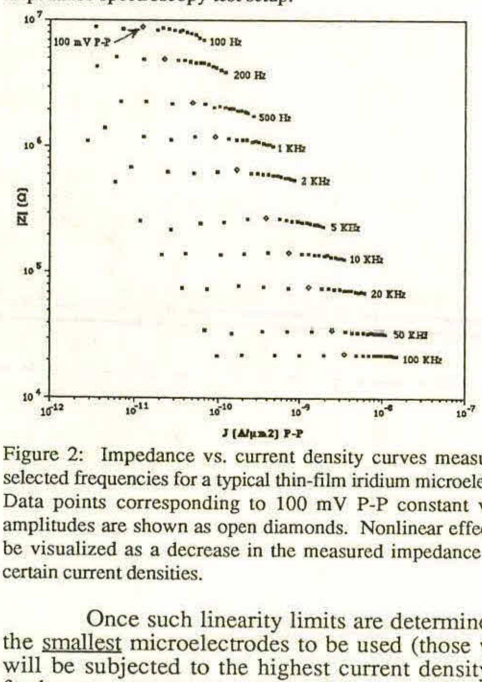

Figure 2: Impedance vs. current density curves measured at selected frequencies for a typical thin-film iridium microelectrode. Data points corresponding to 100 mV P-P constant voltage amplitudes are shown as open diamonds. Nonlinear effects can be visualized as a decrease in the measured impedance above certain current densities.

Once such linearity limits are determined for the smallest microelectrodes to be used (those which will be subjected to the highest current density), all further measurements can be confidently made using constant voltage amplitude techniques. Our results demonstrate that constant voltage characterization can be utilized for small-signal measurements rather than the considerably more cumbersome constant current amplitude alternatives.

Large-signal characterization of microelectrodes for neurostimulation applications must be carried out using signals which are more representative of those actually used than low-amplitude sinusoids. While there is some debate in the literature, neurostimulation is generally carried out using biphasic constant-current pulses [2]. It is logical to test such microelectrodes with these waveforms rather than simply increase the amplitude of the sinusoidal test signals described above. One major reason why this would not be comparable is that the large-signal equivalent circuit for a microelectrode is determined by electrochemical reactions, which are inherently nonlinear and often irreversible. Therefore, the simple superposition of the response of a microelectrode to sinusoids a different frequencies cannot accurately represent its response to a biphasic square-wave pulse. While the details of microelectrode characterization for stimulation is beyond the scope of this paper, it is noted that Anderson, et al [3] describe an *in vitro* test system and Liang, et al [4] discuss *in vivo* characterization.

CONCLUSIONS

The small-signal microelectrode characterization technique presented has been shown to be repeatable, simple to implement, and capable of providing increased confidence in the results due to on-line verification of the linear behavior of the device under test. This approach, in combination with large-signal characterization methods, is being used to study techniques for lowering the impedance of iridium microelectrodes, such as electrochemical roughening, electrodeposition of porous iridium films and "activation" of the iridium (the formation of an anodic oxide layer by electrochemical cycling).

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MAKING THE GRADE: THE MATCH BETWEEN THE TECHNOLOGIES OF TWO PERSONS

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ABSTRACT

Technology has overwhelmed the world, allowing life task equalization for persons with disabilities and permitting improved productivity for everyone. To date much has been written regarding matching man with machine, but little has been said about the match between two technological systems, each a carefully selected, reliable match for an individual. This paper discusses a dual case study in a university setting demonstrating one method of providing a match between two people and their chosen technology.

METHODS

With a PhD in Education and emphases in Instructional Technology and Educational Psychology, C.N. is a tenured university professor with a visual disability which allows visual performance at the two percent level. For years he has used Apple IIe computer system, both at home and work, and often carries software between the two machines. C.N. added Echo IIb Speech Synthesizers from Street Electronics Corporation, P.O. Box 50220, 1470 East Valley Road, Santa Barbara, CA 93150 (805) 565-1612 to both computers and has been successful in adjusting the pitch and rate of speed to improve his own recognition rate of the synthetic speech. He selected Word-Talk, available from Computer Aids Corporation, 124 W. Washington, Lower Arcade, Fort Wayne, Indiana 46802 (219) 422-2424, as his word processing software. Word-Talk, a full featured word processor including many editing and printing capabilities, allows the screen to be read in characters, words, lines, complete sentences, or in its entirety and can be purchased for Apple or IBM PC or XT computers or true compatibles.

A.L. is a graduate student. Since 1986 a constant companion has been her cognitive prosthesis, a 4.5 pound Tandy Model 100 to which a memory upgrade was installed to increase the RAM to 256 kilobytes. The Model 100 (replaced by the Model 102), with a flat LCD screen that displays 40 characters by eight lines, has interface ports for parallel, serial, cassette, and bar code devices as well as a built in 300 baud modem. ROM resident Microsoft software includes BASIC, a telecommunications package, a scheduling and address file, and a rudimentary word processor. Files developed in the BASIC or word processing mode are saved in battery backed RAM. Until recently saving materials written was primarily in hard copy form as the crude cassette method proved unreliable. LAPDOS II, a TSR program and a serial cable with both a nine and 25 pin null modem connector purchased from Traveling Software, Inc., 18702 North Creek Parkway, Bothell, Washington, 98011 (800) 343-8088, is a general purpose file management utility that permits the connectivity between a notebook computer (Tandy, NEC, or Olivetti) and comes in either IBM PC/MS DOS or Macintosh versions. Allowing copies to be transferred from one computer system to another and other file management tasks such as renaming, viewing, and deleting, LAPDOS II also supports a portable disk drive (with an included cable adaptor) for the notebook computer.

The two individuals met in the first class of a doctoral core curriculum; C.N. is the professor and A.L., his student. As with all of his students, C.N. permits various options to submit written assignments including hard copy (read by a human with sight) and tapes (audio and video). When A.L. asked about turning in computer disk, C.N. replied that he had been awaiting the opportunity to try.

RESULTS

Although C.N. and A.L. were both well suited to their own computer systems, proven to be dependable and trustworthy over time, the match between their divergent types of technological devices took some problem solving. Once the Model 100's files were saved to disk on the IBM PC/MS DOS compatible computer system, a final conversion was needed to transfer the information from this format to the Apple ProDOS format required by Word-Talk.

Converting ASCII files from IBM PC/MS DOS to Apple II and vice versa now can be accomplished in different ways. Since Trackstar 128, an internal 65C02 coprocessor board, has been a part of A.L.'s IBM PC compatible, the file transfer program that is part of the utilities was utilized. Trackstar 128, one of three Trackstar boards available from Diamond Computer Systems, Inc. 1225 Tiros Way, Sunnyvale, CA 94086 (408) 736-2000, offers an 80 column mode, 128 kilobytes of RAM, RGB and composite video output, double high resolution graphics, Apple type 16 pin and joystick ports and supports Apple DOS 3.3, ProDOS, and Apple Pascal. Trackstar can access the internal disk drives, serial, and parallel ports of the IBM PC/MS DOS host computer.

To transfer the file from MS/PC DOS to Apple, the Trackstar TSR Star program is run, the high compatibility mode selected, the Apple DOS 3.3 disk booted, and the file transfer program run from the Trackstar disk. The files are converted once the file transfer utility is entered, the format for transferring IBM to Apple set up, the text file mode chosen, and the disks placed in the appropriate drives. The only step left is the conversion from DOS 3.3 to ProDOS since Word-Talk requires the latter format. This last conversion can be completed in many ways. Because of familiarity, the method selected was via one of the many featured copy programs, and files were transferred from DOS 3.3 to a ProDOS preformatted disk.

Using a plastic braille slate and stylus, A.L. put the finishing touches on the assignment by brailling the label. At his leisure C.N. read A.L.'s assignments utilizing Word-Talk and with Word-Talk's capabilities, had the option to add comments at the end of A.L.'s paper. However, in the interest of providing speedy feedback, C.N. opted to use a audiorecorder to tape an ongoing discussion that was played back in A.L.'s car cassette player on the trip after class.

DISCUSSION

Using a modem between the two systems was determined to be another viable option, but was overruled in favor of the method utilized because the somewhat costly modem method did not provide A.L. the satisfaction of turning in material with the rest of the class. There are many variations on this technological theme and multiple options for each idea. Although many persons with disabilities have not been assessed and matched with appropriate systems, many individuals have been utilizing technological equipment and may need reassessment when new opportunities to be interfaced with the technology of a different type become available.

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ALTERNATE INPUT DEVICES: A COMPARISON OF TWO EXPANDED MEMBRANE KEYBOARDS

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ABSTRACT

When the keyboard, the standard input device of personal computers, presented new barriers for persons with disabilities, products were developed to work in the place of the keyboard. Some alternate input devices interface directly to the computer and need specially written software, other products are transparent to standard software programs, but require the additional purchase of a keyboard emulating interface (KEI) for utilization. This paper discusses two expanded membrane keyboards that require interfacing to KEIs. Using a case study to typify characteristics, the features and capabilities of the Unicorn Expanded Keyboard and the Florida Expanded Keyboard are compared.

INTRODUCTION

In the early 1980s the first of the surviving KEIs, the Adaptive Firmware Card (AFC), was developed by Adaptive Peripherals, Inc., 4529 Bagley Avenue North, Seattle, WA 98103, 206-633-2610, to permit persons with physical disabilities the opportunity to access the Apple II computer system, one of the first computers developed for home use. The AFC is marketed by Don Johnston Developmental Equipment, PO Box, 639, 1000 N. Rand Road, Building 115, Wauconda, IL 60084, 800-999-4660 and is also available from ComputAbility Corporation, 40,000 Grand River, Suite 109, Novi, MI 48050, 313-477-6720 and Exceptional Computing, Inc., 450 N.W. 58th Street, Gainesville, FL 32607, 904-331-8847. Among a wide variety of alternate input options, the AFC offers a port to interface alternate keyboards. Soon after the AFC was developed, the Unicorn Expanded Keyboard was designed as an alternate device to work in conjunction with the AFC. The Unicorn, now interfaceable to a variety of KEIs, has become the industry standard which other alternative keyboards, both expanded and contracted, are designed to emulate.

UNICORN KEYBOARD

The Unicorn Expanded Keyboard, was developed by Unicorn Engineering, 6201 Harwood Avenue, Oakland, CA 94618, 415-428-1626 and is available from Don Johnston Developmental Equipment, ComputAbility Corporation, and Exceptional Computing, Inc. Two models have been developed. Both measure 21.25 inches by 14.25 inches and .25 inches thick with active areas measuring 19.75 inches by 9.75 inches. The two keyboards have 128 programmable keys, but the newer device, the blue Unicorn Expanded Keyboard II, has keys that are 1.125 inches square with .125 inches between the keys. The older, yellow keyboard, the Unicorn Expanded Keyboard I has 1.75 inches square keys with .5 inches between the keys.

FLORIDA EXPANDED KEYBOARD

The Florida Expanded Keyboard (FLEK), is available from Exceptional Computing, Inc. This expanded membrane keyboard is built within the shell of a Power Pad, but is fully Unicorn compatible. The device measures 19 inches by 16.75 inches and is 1.75 inches thick. Each of the 128 keys are .625 inches by 1.5 inches on an active area that measures 12.5 inches by 12.5 inches and there is a six inch handle built into the device placed to the left of the active area.

KEYBOARD COMPARISON

Because the FLEK was designed to be completely compatible with the Unicorn, the keyboards and cables can be used interchangeably. The programming capabilities are the same and, with the purchase of a membrane board cable, both devices can be interfaced to the ACS (Adaptive Communication Systems, Inc., 354 Hookstown Grade Road, Clinton, PA 15026, 412-264-2288), products based on the Epson HX-20 computer including RealVoice, ScanPac with RealVoice, EvalPac with RealVoice, and SpeechPAC (1).

Besides the AFC, both devices can be used with various KEIs (2) including the Keyboard Expander and Multi-Access

Package KEIs from Regenesis Development Corporation (4381 Gallant Avenue, North Vancouver, British Columbia, Canada V7G 1L1, 604-929-2414) for IBM MS/PC DOS computers; the PC Serial AID KEI, from DADA (1024 Dupont Street, Unit 5, Toronto, Ontario, M6H 2A2, 416-533-4494) and marketed by Don Johnston Developmental Equipment Inc., Exceptional Computing, Inc., and ComputAbility Corporation, and TASH (70 Gibson Drive, Unit 12, Markham, Ontario, Canada L3R 4C2, 416-475-2212) for IBM MS/PC DOS computers; the Turboselect KEI from Venture Technologies Inc. (304-134 Abbott Street, Vancouver, British Columbia, Canada V6B 2K4, 800-663-8931) for IBM MS/PC DOS, Apple IIgs, Macintosh, Amiga, Atari 520ST and 1040ST computer systems; and the AID+Me KEI from ComputAbility Corporation for Apple IIgs, IIe, Macintosh, and IBM MS/PC DOS OS/2 computers.

One difference between the two keyboards is the area designed for programming. On the FLEK every point of the board may be programmed; there are no dead areas between active keys. In an attempt to decrease dead areas, Unicorn Engineering first came out with a "Dead Spot Eliminator" overlay that concentrated pressure over the keys and then with the newer Unicorn with larger keys. Though the keys are closer together, the Unicorn Expanded Keyboard II has some remaining dead areas. Another difference is in key size and shape. The FLEK's keys are rectangular whereas the Unicorn has square keys.

Amanda is a three year old girl with a diagnosis of muscular dystrophy resulting in decreased physical endurance. Rather than purchasing a contracted keyboard to assess her functional performance, a small keyboard was programmed in the corner of each of the two expanded membrane keyboards. A 35 key block takes up 8.75 inches by 6.25 inches on the Unicorn and a smaller space, 5 inches by 6 inches, on the FLEK. Since the fingers of a three year old are small, the lack of dead spots on the FLEK was another advantage for Amanda. When Amanda becomes more proficient on the modified keyboard, a contracted keyboard will be recommended to funding sources.

The last of the differences is the price: the FLEK was developed with cost in mind and has a lower price tag than the Unicorn. The facility or individual that cannot afford a Unicorn keyboard may be able to purchase the FLEK, a durable, well engineered, alternate input device.

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A Multi-Functional Computer-Based Cognitive Orthosis For A Traumatic Brain Injured Individual With Cognitive Deficits

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INTRODUCTION

Computers serve as an external aid providing cognitive support for managers and professionals. This paper addresses the problem of providing cognitive support for individuals with enduring cognitive deficits from traumatic brain injury. There has been several decades of work on external cognitive aids (Wilson and Moffat, 1984). Recently, a few investigators have applied computer technology to the problem of external aids for memory and constructional deficits. The term "cognitive orthotic" has been applied to computer-based external aids because of the difference in scale and scope compared to manual external aids. Some have focused on task guidance and cuing in well-structured everyday tasks (Kirsch et al, 1987; Levine et al, 1989) while others have focused on support for scheduling, a relatively unstructured task (Henry et al, 1989). Additionally, Chute et al (1988) have proposed that the constellation of deficits associated with head trauma may require a prosthesis to be multi-functional.

The present research approaches the issue of support for cognitive deficits as a problem in computer human interaction. The interface is the user's access to computer system functionality, i.e., provides input to the application and receives output from the application. The performance of the interface depends on three sets of variables 1) user characteristics, 2) task and situational characteristics, and 3) computer system characteristics.

Our approach to the problem is taken in part because of the importance of cognitive structures and processes to interface design. Cognitive deficits could cause a failure in the interface, reducing the ability of the software to deliver its underlying functionality. It was believed that the failure could be resolved by a good match between user's cognitive capabilities and interface characteristics.

There are several interface performance measures which are appropriate to the evaluation of systems for cognitively impaired users. Among them are: 1) learning time 2) knowledge retained from 1 training session to the next, 3) number of user errors, 4) time to recover from errors, 5) time to complete task, 6) endurance (working time without fatigue or stress), 7) working memory load, and 8) robustness (ability to perform under shifting conditions).

Self-Sufficiency

A Self-Sufficiency Model is presented as a means by which interface design can help individuals with cognitive deficits perform target activities. The model addresses the situation where a TBI individual relies on care-givers for the performance of a task which could be easily done alone before the injury. We have defined self-sufficiency to mean that the individual can effectively perform a targeted task with the support of a computing environment.

This case study demonstrates the application of the model and measures to an individual with enduring cognitive deficits. It also demonstrates the use of a computer-based cognitive orthotic in a field setting, i.e., in the Subject's apartment over a period of 12 months.

METHODOLOGY

This is a system design and development effort which is conceptualized as a single subject case study quasi-experiment. The quasi-experiment was possible because of the Subject's pre-intervention computer and software which was used as an adaptive strategy during the previous two years. This implementation had failed, and is the basis of the pre-intervention evaluation and data. Sources of failure were identified, and a new intervention (computer system) designed to overcome those deficiencies. We chose to view the failure as a failure of the technology design rather than a failure of the individual.

The subject is a 54 year old woman, 4 years post-trauma, a fairly typical traumatic brain injury (TBI) constellation of debilitating cognitive disturbances in: attention and concentration, planning, organizing and sequencing, executive functions, endurance, memory and reasoning. She has an impressive left neglect, with associated scanning defects; she was left dominant prior to her injury. She retained left hemisphere functions including language, spelling and calculation skills, color appreciation, and interpersonal skills. She has a graduate education. This Subject was selected in part because there were no further rehabilitation options which promised additional behavioral/functional improvement.

Data collection included system logs, videotaped design and usage sessions, and interviews with the Subject and the Subject's in-home aide interview.

Pre-Intervention System Performance

The data showed, among other interface usage problems, that the user:

- O Frequently forgot what work she wanted to do because of the demands of the computer and application start up process.
- O Was unable to understand and navigate "user friendly" interface features.
- O Was unable to feed or retrieve output from the printer
- O Experienced pain after a few minutes of software use
- O Became exhausted after 60 ± 15 minutes (3 sessions).
- O Lost self-esteem through reinforcement of individual's limitations.
- O Was frustrated at the inability to effectively use a prescribed computer system.

In short, the Subject was dependent on her aide to use the personal productivity software which was supposed to give her greater independence.

The Intervention

Computer Human Interaction concepts were applied to design the intervention and its target performance measures. The intervention system was designed and implemented using rapid prototyping. The design of individual screens was tested in a number of design sessions. Screen design was evaluated on state to state transition time, level of pain, as well as self-reports of confusion by the Subject. Sessions were limited to about half-an-hour. Redesign and modification continued for months after each module was introduced. Some modifications were aimed at improving interface performance, especially reducing energy required. Some modifications allowed the Subject to use application features which had been hidden from her.

Two applications were initially anticipated. The home finances program is a structured task, similar to the task guidance systems (Kirsch et al, 1988; Steele et al, 1989). The text editor is an unstructured activity, yet one which can provide substantial cognitive support (Abbot et al, 1989). Two other applications were added, a time orientation window and a TO DO list.

The computer system consists of an IBM PS/2 Model 80 using a multi-tasking operating system, color monitor, reconfigured keyboard, and Hewlett-Packard DeskJet printer. A special check form was also designed. The system is always on, although the Subject uses a power switch attached to the printer and monitor.

RESULTS

The Self-Sufficiency Model is supported for each application when unassisted usage is documented without evidence of failure. The system data log provides evidence that the Subject was using the applications at a time when she was unattended, or family members were asleep. Further supporting self-sufficient use were work products, self-reports by the Subject and by the Subject's companion. The results are summarized as follows.

O The design goal of learning applications by the end of 3 30-minute training sessions was achieved for the text editor and finance applications.

O Self-sufficiency in text editing was achieved. The Subject demonstrated substantial self-sufficient use of the text editor at all hours of day and night. She uses the text editor for a variety of purposes, including writing lists to herself for things to do, purchase, or remember; taking notes during telephone conversations; and writing letters and memos to her family and friends.

O Self Sufficiency in home finances transactions was achieved. The Subject was able to write her own checks, examine account history, make deposits, and record bank card withdrawals.

O The Subject showed an increased comprehension in time orientation.

O Has increased her self-esteem, and produced a sense of pride, that were substantially greater than anticipated.

There were also results which went beyond the design objectives. The Subject:
1) recognized features of her face for the first time since her accident 4 1/2 years earlier; 2) began to manage her monthly cash flow; 3) the emotional tone in her household changed from one of constant chaos to one which is considerably calmer; and 4) had the capability of providing emotional support for her daughter during a difficult period.

System logs showed patterns which suggested that the Subject had failed to properly perform the bill-paying task. However, work products and reports from the Subject and companion suggest appropriate though unanticipated behavior. The Subject discovered ways to use the software which allowed her to do tasks that had been unintended by the designers and clinicians. Among them were 1) proofreading names, addresses, and account numbers which were in a database used by the finance application, 2) checking bank balances, 3) checking histories of merchant accounts without writing a check.

DISCUSSION

This study supports the contention that interface design can serve as a basis for the design of a cognitive orthotic. A reliance on Computer-Human Interface concepts and performance measures allow the clinician to specify clinically desirable objectives and translate them into system performance. Equally important, the framework can be applied to identify applications -- particularly commercially available applications -- which can cause physical and emotional harm. The study found considerable customization was necessary in order to "fit" the prosthesis to the Methodological differences between this field study and other studies using an experimental approach should be noted. First, the Subject developed additional uses of the prosthetic software which went beyond designers' specifications and intentions. The Subject's behaviors viewed from the system log were initially interpreted as a failure. In fact, the Subject's ability to manipulate the system to serve her needs is highly desirable. Second, some effects emerged rapidly after system use began, while others took many months to emerge. The field design provides the careful research to identify unanticipated outcomes.

The study demonstrates the feasibility to building a prosthesis, and having it become part of a TBI individual's life. Several applications -- treated as replications -- were selected because of their clinical appropriateness, and were able to show the same pattern of results. Thus multiple applications from a single system were tested. The subject succeeded at self-sufficiency for targeted activities.

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A Simple Modification to a Trackball to Provide Computer Access for Individuals with Limited Upper Extremity Function

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Abstract

The use of computers in the rehabilitation, education, and vocation of severely disabled individuals is a well established practice. One of the obstacles the disabled person must frequently overcome is the user interface. This paper describes how the trackball has been used by our rehabilitation technology team to provide individuals with limited functional upper extremity control, who can not operate the trackball with their hands. One complete case study is presented.

Introduction

The use of computers by disabled individuals has increased greatly in recent years. Computers allow people to communicate, work, play, learn, and accomplish tasks that would otherwise be difficult or impossible. With the invention of adaptive equipment such as expanded keyboards, switch interfaces, and special hardware such as the Adaptive Firmware Card and the P.C. Serial Aid, access to computers for the disabled population has become much easier (1). A trip to the local computer store reveals that there has been an increase in the development of commercial devices intended for use by the able-bodied population. The trackball is one such device. The trackball, however, has also proven useful to disabled individuals as an alternate input device (2).

A trackball is a pointing system which replaces a mouse in applications which require a mouse. The trackball is essentially a stationary mouse. To move the cursor on the screen, the user simply rolls a ball which is held in place by a cup. Many of the commercially available pointer systems on the market emulate the device they are to replace (1). This means that the computer does not know the difference between the standard pointing system (for example, the mouse) and the replacement pointer system (the trackball). This is very useful information because this means that the device should work with the same software and hardware as the device it replaces.

Our rehabilitation technology team has been working with disabled individuals to provide access to computers. This paper describes our implementation of a modified trackball.

Case Study

Stephanie is an eight year old quadriplegic on a ventilator, who uses a chin control to drive her power wheelchair. She has been mainstreamed in a second grade class, and required a computer to assist her with her work.

The first step was to determine what Stephanie wanted and needed to accomplish with the computer. After consultation with Stephanie, her parents and teacher, it was decided that a system which would allow her to scan her schoolwork into the computer, write or color, and print out the completed work was desired. This would require a computer, image scanner, appropriate graphics software, and a graphics printer. A preliminary report from the occupational therapist suggested investigating several computer systems, one of which was Macintosh CX. The parents purchased the Macintosh CX without consultation with the therapist. This left us with an interesting question: what interface to use?

Stephanie was evaluated for an appropriate access site by an occupational therapist which included a screening for proper positioning. Stephanie has incomplete quadriplegia and has very limited range and strength in her upper extremities, but has good head control. The use of the standard Macintosh mouse was eliminated, because of the lack of range in her arms. Use of her limited hand control was investigated by trying a trackball pointing device with her hand. The trackball requires less overall hand movement and she could move the cursor using the device, but she could not use the buttons effectively.

Since Stephanie has good head control and uses a proportional chin control to drive her wheelchair, the trackball was positioned at her chin to see it she could operate it. She proved surprisingly proficient almost immediately. It was decided to try the Kensington Turbo Mouse, a Macintosh compatible, mouse emulating trackball. Although this worked well, modifications were necessary to facilitate long term use. The device needed to be shortened so as not to interfere with Stephanie's tracheostomy tube and the buttons needed to be raised to allow easier activation.

Upon inspection of the device, it was decided that shortening the case would require cutting or bending the printed circuit board inside the case, which was not feasible. Instead, rehabilitation engineering suggested that the device be tilted in front of Stephanie, with a small clip attached to the top of the case to keep the ball from falling out (Figure 1). The clip needed to be easily removable by family or an attendant so that the ball could be removed and regularly cleaned. The buttons were built up approximately 1/2 inch using firm foam, which was attached to the device using velcro (to ensure easy replacement and repositioning). With these simple modifications, Stephanie can operate the trackball with her chin or bottom lip and draw, color, or write on her computer system.

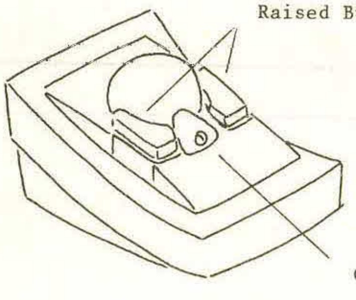

Figure 1: Modified Trackball

Discussion

It has been shown that a trackball can make an effective alternate input device (2). At the time of this paper, we have used the trackball with two other clients. One is a video engineer diagnosed with ALS who has lost functional use of his arms. He controls his computer editing system using a trackball which he operates with his foot. Another client is a high level, complete quadriplegic, who does computer aided drafting for an aerospace engineering company in Southern California. He uses an MS-DOS based computer system which he accesses with a trackball he controls with his cheek. The use of the trackball in the non-traditional positions we have described, has been very effective.

A major advantage of working with a commercial device such as a trackball, is that questions of device compatibility are much easier to answer. As long as an evaluation to determine access problems has been completed, the compatibility question is a computer question which the local computer store can answer. The salesman can usually answer all questions regarding hardware and software compatibility. If questions persist, the device manufacturers have technical support specialists, who can usually say whether the device will work with specific software. Additionally, the use of an off the shelf solution can have the advantages of being quicker to obtain and modify, and can be less expensive than a custom designed solution.

Conclusions

Our experiences with making minor modifications to trackballs and using them with individuals who have little functional upper extremity control, has been very good. These devices are attractive due to their commercial availability, selection, price, and computer compatibility. Trackballs and other devices can be used as effective input devices even when the device can not be accessed as designed.

Acknowledgements

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A PORTABLE 32-CHANNEL DATA COLLECTOR

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ABSTRACT

This paper describes the design and implementation of a V40 (NEC) microprocessor-controlled, 32-channel, portable data collector for recording pre-processed sensor information. The device provides programming capabilities distinguished by four types of sensor calibration procedures, two special sample mode selections, data review functions and transfer to a host MicroVAX II Laboratory Minicomputer (DEC). This unit was designed to facilitate sensor measurements of experiments occurring outside the confinement of the laboratory.

INTRODUCTION

More realistic data from gait analysis can be obtained from paraplegic subjects using functional electrical stimulation as they perform longer walks outside the laboratory. These gait experiments may require multiple sets of sensors, ie. force instrumented walker, force sensing resistors [1], and ankle/knee and hip/trunk goniometers. Also, a means is needed to synchronize this data with the progression of the muscle stimulation patterns. Portable data collectors (PDC) that use non-volatile memory as a storage medium are commercially available, but their applications are limited by their typically low sampling rates and inherently slower serial transfer of data to a portable computer. To address our needs, a portable, battery powered, multi-channel data collector with a maximum 200Hz sampling rate was designed utilizing static RAM (SRAM) for data storage with accommodations for 32-channels of analog and 8 channels of digital sensory input. By using our existing parallel communication interface to the MicroVAX II [2], the data can be quickly uploaded for post-processing applications.

HARDWARE DESCRIPTION

Figure 1. shows the hardware block diagram. The 4MHz CMOS NEC V40 microprocessor-based printed circuit board used in our portable stimulator systems [2] was incorporated into this design because of its generality and tested reliability. The V40's built-in 3-channel counter/timer is used to generate the 1 MHz A/D conversion clock and to set the software's sampling interrupt interval. Two 128K EPROM's are available for the control software and a battery-backed 32K SRAM is designated for the software's variables and user-defined parameters. An additional 256K of volatile SRAM is reserved for sampled data storage.

Four 8-bit, 8-channel data acquisition systems were configured to accept a 0 to +5 volt analog input, providing 19.5 mV bit weight of resolution. All inputs are buffered and externally available through 8-groups of 5-pin single-inline connectors. Sensor output can be easily adapted to this type connection. A 24-channel digital I/O peripheral is sufficient to accommodate three push-button function keys, low-battery detection hardware, and 8 inputs that are available for communication with a portable stimulator [2].

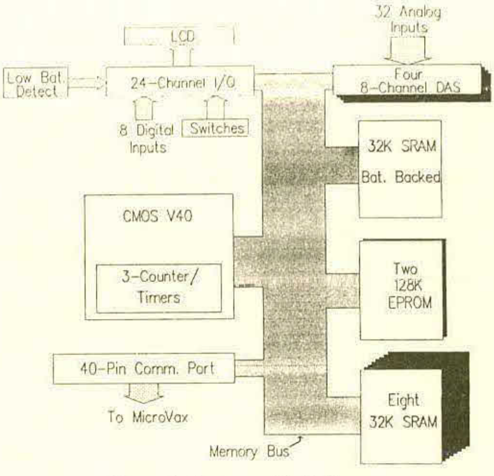

Figure 1. Hardware Block Diagram

The user interface consists of the function keys and a 16-character by 2-line LCD. This LCD format allows for one line to be used as a variable function label for the keys and the other for menu choices and messages.

An 40-pin ribbon cable connector provides an interface to the same communication hardware used by our Laboratory Electrical Stimulation System [2]. This parallel communication uploads a maximum 256K of data to the MicroVAX II in about 15 seconds.

SOFTWARE DESCRIPTION

The 4K data collection program contained in the EPROM of the PDC is written in assembly language. The software is organized into a nested, menu-structured format divided into *Calibration, Sample*, and *Data* menus and related submenus necessary for a typical data collection session (Figure 2.). All user control and programming is initiated through three push-button function keys. A software reconfigurable label on the LCD identifies the keys's purpose. This allows for the same switch to access different functions depending upon the user's location within the menu. An auto-repeat function is active for all keys to promote faster selections within certain menus.

Active channels may be established in the *Channel Set* and *ID Tag Set* submenus of the *Calibration* menu. The *ID Tag Set* submenu enables the 8-channel digital input port so that analog data may be synchronized with stimulator pattern information. The usual *One-point* and *Two-point* calibration procedures are available, along with a *Volt* calibration that computes the gain in volts per A/D units, and an *A/D Units* calibration that sets a gain of 1. The computed gains and offsets may be verified in the *Show* menu. A convenient reset of all parameters is possible by holding down any key when powering the device or by accessing the *Reset* submenu. The PDC

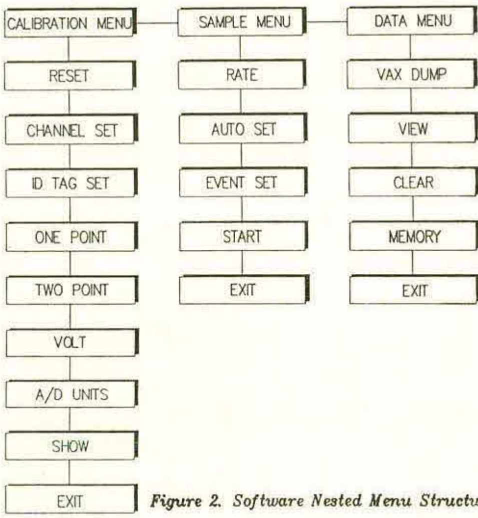

Figure 2. Software Nested Menu Structure.

accommodates two special modes of sampling, along with the default manual start/stop mode. The *Auto Set* mode allows the user to .program the length of the sample and pause states in seconds. This can effectively increase the total sampling time by recording only periodic intervals of a lengthy and often uneventful data collection session. The *Event Set* mode allows the user to specify start/stop trigger conditions for any active channel. A specific event may be captured and stored, allowing for more efficient utilization of the memory. Both modes can be used simultaneously so that a flexible and automatic sampling procedure may be achieved.

The *Rate* submenu allows the user to program the sampling rate from 20Hz to 200Hz. Due to memory limitations, the total sample time, displayed in an H:M:S format, will only be a few minutes when using the maximum number of active channels and highest sample rate. Typical sampling sessions can last 45 minutes for 6 channels of input or nearly two hours for 2 channels of input at 20Hz. The low-battery hardware is monitored upon power-up and when sampling data. Further sampling is inhibited if the low-battery condition persists.

All calibration and sampling parameters are retained when the PDC is powered-down, however the sampled data is not saved because it is stored volatile memory. The sampled data can be transferred to the MicroVAX II by entering the *VAX Dump* submenu and connecting the PDC to the communication interface. By concurrently running the appropriate MicroVAX II software, the trial number, channels, gains, offsets, sampling rate, and raw data information is extracted and placed into a laboratory file that is format compatible with the MicroVAX II data collection files; so the files may be used in other plotting and processing programs. As useful debugging tools the raw data for any trial and channel may be examined in the *View* submenu; all memory pointers are reset in the *Clear* submenu; and the total free memory is displayed in the *Memory* submenu.

CONCLUSION

The PDC has proved to be a valuable tool for acquisition of low-frequency sensor information to aid in gait analysis. The simple three switch/LCD interface allows the user to conveniently program the device, attesting to its true portability. Also, the PDC is used to free the MicroVax II from lengthy data collections , ie. Cybex muscle fatigue testing, that would otherwise considerably slow the system's multitasking response. Future modifications will include memory expansion, A/D reconfiguration for acceptance of +/- 5 volt input, design of a serial communication interface to a personal computer, and sensor pre-processing hardware with programmable gain.

ACKNOWLEDGEMENTS

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Environmental Control for the Severely Physically Handicapped

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P3.16

ABSTRACT

An Infrared controller was built which requires only five switches for operation of up to 16 consumer electronic devices, lights or appliances.

BACKGROUND

Infrared control of consumer electronic devices such as TVs, VCRs, and stereo equipment has become very common. This has led to the development of trainable units that can imitate several infrared controllers. This is a convenience for many by reducing coffee table clutter. For wheelchair users, trainable controllers can be used to reduce laptray clutter, and minimize the range of finger motion required to operate several devices. Most of these trainable controllers have multiple pushbuttons which prevent use by individuals able to operate one or only a few switches.

For this reason, I was very interested in the Master Controller described in Byte Magazine (1).

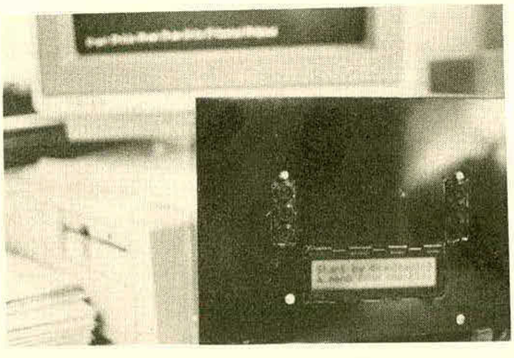

Photo 1. Master Controller connected to the personal computer for command programming.

This unit has six buttons. Two to scroll through up to 16 devices, two to scroll through up to 16 functions, a fifth "Do it" button to send the selected command, and a "Learn" button used only to train the unit. To my knowledge the Master Controller is not available as a completed unit, but the circuit board, firmware and interface software are available from Circuit Cellar Inc. (2)

Electrically, these buttons are scanned by the internal microprocessor in a multiplexed fashion. While the Common Interface Format developed at Trace (3) does have a standard for multiplexed input switches, it is not frequently used. For this reason, transistor output optical isolators were connected across all buttons except "learn". This adaptation allows use of individual switches, common ground inputs such as a five switch armslot control or the control unit of the Tamara System (4) .

While the Master Controller allows control of consumer electronics, this leaves unsolved the problem of light and appliance control. Knowing that the old style ultrasonic BSR X-10 system for light and appliance control uses the same 40 KHz carrier frequency as most infrared controllers, an X-10 hand controller and base receiver were converted to infrared control (BSR has since made an infrared base receiver available, but not a transmitter .) The converted BSR hand controller was used to input the X-10 control codes to the Master Controller. The resulting system is capable of operating most electric or electronic devices found at home.

FUTURE PLANS

Possibilities for the future include several changes:

(1) Use of individual switch input lines to replace the scanned multiplexed switch inputs used, this would eliminate the optical isolators used in the current prototype.

(2) Use of graphics instead of words allowing use by nonreaders.

(3) Option to place the display remotely from the circuit board, this could help visibility if used on a wheelchair.

(4) The present scrolling technique requires two switches for selection of device and two others for function. Once an upper limit or lower limit is reached the opposite switch must be activated to make another selection. Rewriting the software could allow scrolling to "wrap around" once a limit is reached. This revision could reduce the number of switches required to three.

(5) The Tamara system [4] software uses a timing loop to imitate the Do-it switch if none of the select switches have been activated for a preset amount of time. Rewriting the Master Controller software to incorporate this feature would reduce the required switches from five to four (two if wrap around scrolling were used .) This would allow Master Controller use by individuals too physically handicapped to use more than two switches.

SUMMARY

A commercially available trainable infrared controller kit was built. The addition of five optoisolators allow a wide variety of handicapped controls to be connected. BSR X-10 appliance control was added by modifying an ultrasonic transmitter / receiver control set. This system allows handicapped individuals control of most appliances and consumer electronics found at home, thereby increasing their independence and quality of life.

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A COMPUTER-AIDED SHAPE SENSING SYSTEM FOR CUSTOM SEAT CONTOURS

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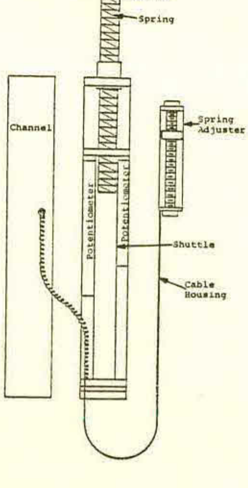
INTRODUCTION

Research shows that custom contoured cushions improve wheelchair seating [1]. An earlier contour measuring system that was limited to passive determination of the buttocks-cushion interface contour with a 2" resolution [2] requires experienced staff to prescribe suitable custom contours. To improve CAD seating, a new Computer-Aided Shape Sensing System (CASSS) has been developed for measurement and assessment of both contour and force (pressure) distributions at the seat interface. The system is designed to allow the formation of appropriate contoured shape and pressure profile by adjusting spring tensions in the individual sensor elements.

METHODS

The CASSS consists of an 11 X 12 array of sensor elements spaced linearly at 1.5" intervals, forming a seat with a 17" X 18.5" area. The seat surface contains 132 acrylic balls (1.5" diameter). Each probe (Fig. 1) was assembled with a shaft, shuttle, channel, spring adjuster, cable and housing. A spring which can be easily placed into the shaft is used to provide a support medium.

Fig. I Probe Assembly



The shaft was capped with an acrylic ball to force the spring against a pusher in the shuttle. Changes of the shuttle position are controlled by a socket-head bolt and nut within the adjuster through the cable attached to the nut and channel. The cable housing was attached to bottom caps of the adjuster and shuttle. Turning the bolt with an electric driver which will move the nut and the shuttle position up or down is used to determine spring tensions. Vertical displacements of the shuttle and shaft were measured by 2 linear potentiometers arranged in parallel with the sensor. The signals are multiplexed through an A/D converter to a PC.

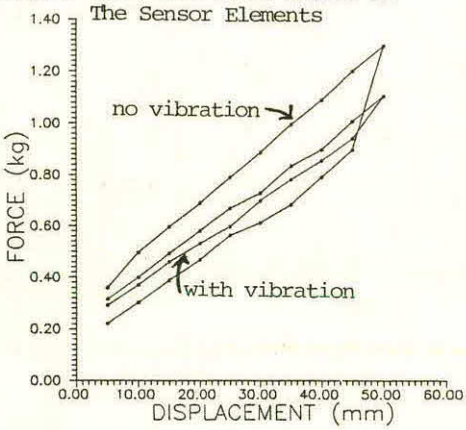
Initially, the shuttles are set at a certain position. After a client is properly seated, an equilibrium contour is determined by recording displacements of the shafts. The force distribution is determined from both the displacements and the shuttle position. Both the contour and force are displayed on the PC monitor. Manual adjustments of the individual sensor probes are used to prescribe a custom seat contour for the particular client's needs. Springs with different stiffness can be applied to provide support media in the appropriate range.

Several springs were designed and studied. Vibration testing was conducted to study friction effects on the spring system. Compression testing was conducted to determine load-deflection relationships for the system performance. Softwares were developed to collect, analyze and display the 3-D contour and the corresponding force distribution.

RESULTS

The motion ranges are 2.5" for the shaft and 1.5" for the shuttle. Seven inch long springs are made of music wires with 0.033", 0.035" and 0.037" dia. for spring constants. The springs are 3/8" outer dia. for each turn and are spaced 5/32" between threads. Load-deflection curves of each probe were calibrated by a LVDT load cell for the springs with and without a vibrator. The inherent friction-induced hysteresis is significantly reduced by the vibrator (Fig. 2).

Fig.2: Load-Deflection Curves of The Sensor Elements



With the vibration, the system was characterized by a linear equation: $F= K*X + [F1 + .96*K* (V-2.5)]$, where K and F1 depended on the spring used. The standard deviations were less than 1% for the spring constant K and 5% for the preload F1 in the 3 springs. X is the vertical displacement for contour indentation and V is the shuttle position for spring tension. The contact force F is calculated from the equation.

Fig. 3 shows a seat contour and the corresponding forces for an able-bodied subject with the 0.035" dia. springs and shuttle positions at a 3 V level. Pressures which were determined from the forces divided by a 1.5" square area were consistent with interface pressures measured by an Oxford monitor.

Fig. 3a: A seat contour of normal male (80Kg) measured from the system

Contour (mm)

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	8	17	21	21	17	8	0	0	0
0	0	4	20	26	27	26	27	21	8	0	0
0	0	9	22	31	27	26	31	24	11	0	0
0	0	9	21	27	22	19	25	21	10	0	0
0	0	9	15	19	10	6	15	16	10	0	0
0	0	6	10	11	2	0	7	9	7	0	0
0	0	5	6	5	0	0	3	4	4	0	0
0	0	7	6	1	0	0	0	3	3	0	0
0	0	6	5	0	0	0	0	4	5	0	0
0	1	7	9	0	0	0	0	9	9	0	0

Fig.3b: Force distribution with respect to the contour of Fig. 3a.

Force (10*kg)

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	8	10	11	11	10	8	0	0	0
0	0	7	11	12	12	12	12	11	8	0	0
0	0	8	11	13	12	12	13	12	9	0	0
0	0	8	11	12	11	11	12	11	9	0	0
0	0	8	10	11	9	8	10	10	9	0	0
0	0	8	9	9	7	0	8	8	8	0	0
0	0	8	8	8	0	0	7	7	7	0	0
0	0	8	8	7	0	0	0	7	7	0	0
0	0	8	8	0	0	0	0	7	8	0	0
0	7	8	8	0	0	0	0	9	8	0	0

DISCUSSION

The simple linear CASSS has improved the contour resolution. Springs in the probes can be quickly changed to provide the proper range of contour indentation for clients with various disabilities and seating needs. A contour and the corresponding force can be measured within 1 min. A simple adjustment of the individual probes allows the prescriber to formulate an appropriate custom contour by updating contour and force profiles. The decisions for the custom contour may be based on the depth and shpae of the contour and the pressure. Asymmetric seating, body deformity and other seating needs will also be considered. The CASSS provides a simple, rapid and inexpensive feedback method for the prescription of customized seat contours.

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MODIFYING OFFICE CHAIRS FOR PEOPLE WITH SPECIAL NEEDS

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Conventional office chairs come in a range of styles and features. Adjustable seat and back height are commonplace, and a few models offer adjustable armrests, seat depth, and tilt options. All this adjustability means an increased number of individuals are comfortably accommodated. When working with people with disabilities or limiting conditions, however, modifications are often necessary. The customized chair can provide needed postural support or stability and assist in positioning the individual for optimal task execution, as well as alleviating positions which induce pain or discomfort. The following paper presents some of the modifications that we have done to adapt conventional office chairs to individuals with special needs and the design criteria that were used. The case studies that these adaptations are drawn from include people with cerebral palsy, osteogenesis imperfecta, post-polio syndrome, spina bifida, thoracic outlet syndrome and neck and back injuries.

GENERAL DESIGN CRITERIA

Comfort: In many cases, designs were chiefly inspired to reduce pain and discomfort.

Durability: Provide product that is at least as durable as before modification.

Enhance posture: Chair should help person maintain a beneficial and stable posture.

Enhance job performance: Chair modifications can reduce the amount of energy required to stabilize posture. It can also help position an individual for optimal task execution. The distraction and depletion of energy caused by pain and fatigue can be greatly reduced.

Independence: Whenever possible, person should be able to get into or out of chair independently, as well as operate necessary adjustments and access their work.

Safety: Must provide stability while sitting or getting into and out of chair.

Aesthetics: Create product that is as conventional and unmedical looking as practicable. Whenever possible, the individual is responsible for decisions about color, fabric, etc..

Cost: The most cost-effective solution that works well is employed.

Compatibility with job environment:
Factors such as types of casters,upholstery, height of work surfaces, appearance of other furniture, and adaptibility to various work stations are to be considered.

COMMON MODIFICATIONS

Armrests

The most common modification performed was to armrests. We first determined what they were needed for: typically, stabilizing while getting into or out of chair, support for task performance (such as keyboard entry), postural assistance, pressure relief, or resting. Many armrests are not adjustable enough or close enough in to the body to aid in task performance or offer stabilization. Correctly positioned, they can relieve neck and shoulders of having to hold the arms up.

The adaptations included:repositioning, changing size of armrests, changing contours, padding, adding adjustability and swing-away versions.

Postural Stabilization:

Modifications performed for postural stability included: adding or changing contours of seat and back, use of different foams, addition of pelvic bolster, lateral support, anti-thrust wedge, pelvic belt, headrest, adding or changing armrests, and use or addition of footrests.

CASE STUDIES:

Case 1:A person with post-polio syndrome was no longer able to rise from his chair unassisted, due to the deterioration of his shoulders through over-use. The objective was to provide a power lift mechanism to elevate his chair and enable him to rise from itunaided. It also needed to swivel in the low position. The high and low positions needed were very specific and the clearance underneath the seat for the lift mechanism was extremely restricted. The existing gas cylinder was replaced with an electrically-powered hydraulic lift. A guide assembly of hardened rods and linear bearings to resist lateral thrust was installed. The pump was housed in an acoustic shroud to deaden noise. (See figure A)

Case 2:A young woman with osteogensis imperfecta contacted us after being told that she wouldn't be able to be a beautician because of her physical condition. An assessment was made of the various tasks involved and her physical capabilities and limitations. She was of short stature and had impaired balance. A combination sitting or standing station was designed and fabricated adapting a conventional office chair. The basic chair was selected for several important features: a long gas piston that gave the chair a very broad high and low position, adjustable height armrests, and adjustable back and seat pan. The chair is used in the low position for manicures and facials, and in the raised position for working on hair. We added: a fold-away footrest, tray for equipment, standing platform with casters and floor lock, a standing frame with anterior support and swing-away lateral supports, and casters with thread guards to prevent hair from binding the wheels. We further reduced the seat depth by shimming the back forward. (See figure B).

Case 3: Sometimes an office chair isn't conventional. One person with cervical and thoracic injuries found a large recliner in a semi-reclined position to be the most tolerable The challenge in this case was to provide access to a keyboard and large reference books. Mobility was also desired. A caster base was added in conjunction with a set of rubber-tipped legs that were positioned forward to prevent chair movement when he got into or out of the seat. To make the essential work surfaces accessible, they were mounted to the chair on a removable post that acted as a pivot point for swinging them out of the way.

Case 4: A woman with thoracic outlet syndrome and multiple surgeries due to upper extremity trauma was preparing for training in computer work. She needed a chair that would offer support up to the cervical region and have armrests in a relatively low inclined position. Due to the extremity of her condition, she would not be using her hands, however, the armrests would support her to relieve pain. We were able to locate a chair that relieved stress on her lower back and had a seat pan that fit her large frame. Since a chair with the appropriate upper back support was not available, we merged a custom back with the existing seat (retaining the profile of the lower back). A fitting was conducted to determine the appropriate placement of support. Varying densities and contours of foam were tried until the optimal position was obtained. The armrest positions were determined at that time also. The chair was recovered and special adjustable channel armrests were added. These were mounted on a swivel joint that allowed the incline to be changed with minimal pressure, but retained position under normal use (See Figure C).

CONCLUSION: The modifications were very specific to the individual, but there has definitely been carry-over from project to project. The requests for specialized chair modifications are increasing and we hope to refine and expand our repertoire of adaptations We are currently working on a cost-effective system for locking casters and pivot with easily operated controls and devising methods of powered positioning. Future possibilities include obtaining a relatively standard base and modular components that could be assembled in the desired configurations and working with chair manufacturers to design chairs with more adjustability.

ACKNOWLEDGMENTS:
This work was done at the Habilitation Technology Laboratory of Gillette Children's Hospital. The exchange of ideas and information is critical to the success of these designs and was given generously by the staff there. Special appreciation goes to Bruce Tew, Paul Lemke, John Spielman, Larry Isaacson, David Wilkie, Brent Skarsten, and the Assistive Technology and Seating Teams at HTL.

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Figure A

Figure B

Figure C

Turtle Trainer: A Way To Evaluate Power Mobility Readiness

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ABSTRACT

In order to better assess an individual's ability to operate power mobility, a motorized cart with wheelchair tiedowns and with the ability to accept many input controls has been developed. The Turtle Trainer cart allows evaluators to easily determine an individual's potential for power mobility.

BACKGROUND

Proper operation of power mobility involves many factors such as vision, cognition, and selection of proper controls. People unable to self propel a wheelchair can be divided into three categories:

1) Those whom evaluators are sure can operate power mobility
2) Those whom evaluators are unsure whether they can operate power mobility
3) Those whom evaluators are sure they cannot operate power mobility (more on this later)

Evaluators have been seeking a quick and accurate way to determine who in the second group can safely operate a power mobility device.

Until now, evaluating this middle group entailed five choices:

(1) Seating an individual in a power mobility device, not providing the customized seating possibly used by the individual in his manual wheelchair, and hoping for an accurate performance.

(2) Take the time to customize the power mobility seating by inflatable bean bags or other means.

(3) Say it is not possible to evaluate these individuals.

(4) Purchase the individual a power mobility device and hope it can be operated properly.

(5) Use a computer simulation

While several computer simulations (1,2) have been developed to determine a potential user's ability to operate power mobility, it is the author's contention that these simulations are several steps removed from the reality of a wheelchair moving under the individuals control. For these reasons, other methods of easily providing client controlled movement were investigated.

PROJECT DESIGN

Originally, a power base to slip under the rear wheels of a manual wheelchair was envisioned. But during discussion, therapists thought that even one inch of added rear height would create too much of a tilt for some individuals. Therefore a platform large enough to support all four wheels of the largest wheelchair used at the school was constructed. To save width, the motors and casters were placed underneath the platform, and a loading ramp was attached.

Through experimentation, it was determined that operating two ABEC Fireball wheelchair motors at 6 rather than 24 volts provided a desired slow, Turtle-paced speed. Acceleration was smooth enough that variable speed and acceleration were thought unnecessary and the simple control electronics is comprised of 9 diodes, three transistors, and three relays. To allow use of a wide variety of input controls, the electronics were wired to accept Du-It controls such as a joystick, touch disk, vector scanner, and individual switches.

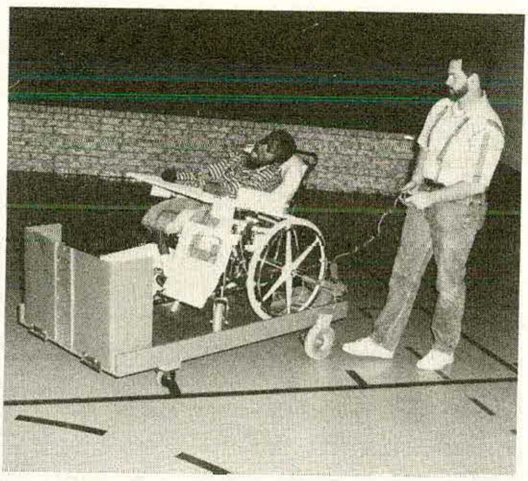

Photo 1. Turtle Trainer in use by client, the staff member is holding the shutdown switch.

To date the Turtle Trainer has been used by several individuals. The trainer is large enough that the therapist working with a client was able to sit on it and hold the user control in a variety of positions to find optimum placement.

By providing the kinesiological input and changing perspectives not available with computer simulation the Turtle Trainer provides a truer simulation of power wheelchair control. Although a formal study has yet to be conducted, evaluations using the Turtle Trainer should prove more accurate than evaluations using computer simulations.

Even those in the third group (clients the evaluators are sure cannot use power mobility) can use the Turtle Trainer as a switch control modality for on off movement control instead of controlling a toy or appliance. In our experience at the school, many clients in the third group surprise us and we continually look for indicators of power mobility readiness.

SUMMARY

A powered cart was constructed allowing evaluation of clients ability to operate power mobility without changing the individuals seating system.

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Mutha: A Microprocessor Based Timer For SCI Pressure Relief

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ABSTRACT

A microprocessor based timer was constructed to remind (like a mother), one of the authors to perform regular pressure relief after decubitus repair surgery.

Rather than using mechanical or electronic timer circuits, a microprocessor based system was developed.

BACKGROUND

Presently there is a notable lack of any type of reminder for assisting in decubitus relief. For initial recovery after a second surgery, the doctor recommended that an author spend one hour laying down for every two hours that were spent in the wheelchair. Post recovery, an authors plastic surgeon was consulted and a timing ratio of 15 seconds push up for 15 minutes sitting was considered sufficient relief to replace the earlier pressure relief procedure. Before this project was completed it was required to set a digital watch alarm for the required time between pressure reliefs.

A review of the relevant literature shows Cumming et al (1) to have developed a microprocessor based unit to record weight shifts and/or remind users to shift weight every 15 minutes for at least 5 seconds. The device was built primarily for research and showed users did not normally perform weight shifts without prompting. Cumming et al did not pursue further development because the population of SCI clients they worked with dropped dramatically (2). Hurwitz et. al. (3) described a pressure sore prevention program and microprocessor based monitor, but appeared to ignore the potential of a reminder that "nags" the user to perform pressure relief.

Burn et. al., (4) in describing a pressure relief monitor suggest the need for regular pressure relief, but only monitor what the patient is doing relative to pressure relief, and yet do nothing to facilitate the process.

PROJECT DESIGN

System requirements:

1. Small and light enough to fit onto a manual wheelchair.

2. Self contained power supply.

3. Construction that would withstand daily active use.

4. Modular construction to facilitate construction and repair.

Rather than use a simple mechanical or electronic timer, the need for a flexible timing system was considered, and it was decided to develop a microprocessor based system.

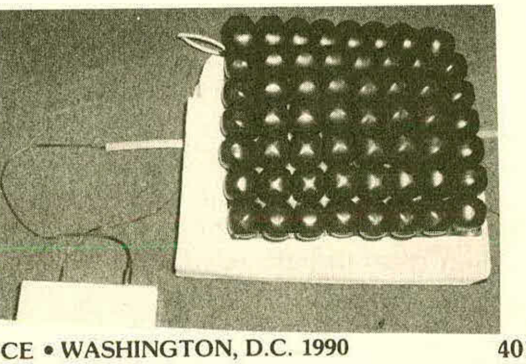

Photo 1 shows the microprocessor unit connected to a length of pressure sensitive tapeswitch. The tapeswitch is placed under the contoured foam and Roho cushion. In actual use, the wheelchair seat is replaced by ABS plastic, a short length of tapeswitch is placed on the seat and covered by another layer of plastic. The slightly contoured foam is added, and the user sits on the ROHO cushion.

System software needs included:

1. Ease of programming (the Forth language was known by one author and seemed appropriate for the project.

2. A buzzer which could not be turned off by anything other than a weight shift for the required amount of time. Presently, Mutha will beep after 15 minutes, then reset and beep twice after a 15 second weight shift. This timing was recommended by the plastic surgeon of one author.

3. Flexibility in down loading to the Mutha hardware. The system is currently accessed by an IBM AT clone and an Apple Macintosh.

4. Ability to place the software in permanent memory such as an EPROM.

FUTURE PLANS

Two improvements are possible:

(1) The single seat pressure switch could be replaced with one or more pressure transducers (The 68HC11 microprocessor used has eight channels of 8 bit A/D built in), and the software could integrate pressure over time for one or more seat regions and alarm when the integrated pressure-time exceeds that of a preset limit.

(2) The simple electronic buzzer used in the first unit could be replaced by synthesized speech reminders, possibilities here are limitless, including the users voice, his mother's, doctor's, coworkers', or a random presentation of these .

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ACKNOWLEDGEMENTS

The authors would like to thank Rick Masters for his assistance in formulating and debugging the software.

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Cushion Evaluation based on Stress Distributions in Soft Tissues

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ABSTRACT

Cushions are usually prescribed by clinicians to reduce internal tissue stresses so as to prevent bedsores or pressure sores. For the present study, a 2-Dimensional physical "bone-tissue-cushion" model was developed. This model was used to evaluate the effectiveness of various cushion materials (foam, gel, air, wooden surface) in reducing internal stresses in the soft tissue. Results indicate that the foam cushion was effective in reducing the shear stresses in the soft tissue when compared to the gel cushion, air cushion and the wooden surface. The enveloping property of the cushion played an important role in the internal stress distribution of the soft tissues.

INTRODUCTION

During sitting or reclining, normal individuals relieve stresses that are potentially damaging to their tissue by unconsciously adjusting their posture. Patients with a loss of sensation, such as those with spinal cord injuries, do not sense or relieve these stresses and are prone to develop bedsores.

Bedsores are localized areas of cellular necrosis formed as a result of prolonged excessive mechanical stresses in soft tissues. External pressure on soft tissues generate internal stresses and over an extended period of time, can cause mechanical damage in tissues. The pathogenesis of this severe complication involves biomechanical factors such as the type, magnitude and duration of the stresses (Kosiak 1961). The type and magnitude of stresses generated in the tissue depend on body build and and types of cushions used to support the body (Garfin et al., 1980; Garber and Krouskop, 1982).

There is a wide variety of cushions available specifically designed for extended use in wheelchairs. Clinicians have heavily relied upon the tissue-support interface pressure measurements for cushion prescriptions while neglecting the state of internal stress distributions in the soft tissue. Moreover, cushion manufacturers supply inadequate quantitative information about cushion effectiveness. In order to obtain a measurement of the internal stresses in the tissue noninvasively, a physical model was developed to compare cushion performance in terms of stresses generated in the model soft tissue.

METHOD

The model soft tissue comprised of PVC gel simulating the "soft tissue" which was cast around a rounded edge wooden core representing the the model "bone". The PVC gel was cast such that it formed a semi-circular slab of model soft tissue (fig 1). Small holes were etched on the surface of the model soft tissue (PVC gel), and were filled with black ink forming a cartesian grid.

Experiments were conducted with the bone-tissue model indenting rectangular slabs of different cushion materials. Photographs of the unloaded (undeformed grid) and loaded (deformed grid) model were taken. From the grid displacement data obtained from the photographs, finite strains and then the shear stress distribution in the model soft tissue were calculated.

RESULTS

The foam cushion was effective in reducing the shear stress magnitudes in the soft tissue followed by the air cushion, the gel cushion and the wooden base. The maximum shear stress developed in the soft tissue model due to the different cushions are as follows:

foam- 1.08 kPa; air- 1.29 kPa; gel- 1.78 kPa; wooden base- 2.28 kPa(figs 2-5). Moreover, foam cushions distributed the stresses more evenly when compared to the other cushions. The wooden surface generated dangerously high magnitudes of shear stresses in the model soft tissue.

The stress distributions revealed the importance of enveloping properties of the cushions. A cushion with superior enveloping property increases the surface contact area and minimizes stress concentrations.

The foam and air cushions exhibited greater enveloping than the gel cushion. The wooden surface had no enveloping property and thus generated high stress concentrations under the bone core. The model also provided an insight to the actual stress regimes that may exist in soft tissues and should aid in the design of wheelchair cushions and in prescription of cushion components for problem patients.

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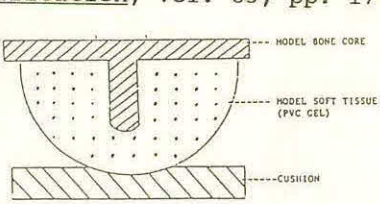

Fig 1.
Soft Tissue Model.

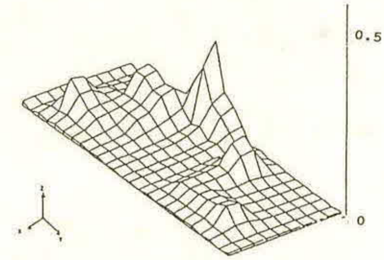

Fig 2.
Shear stress distribution in model soft tissue due to a Foam cushion.

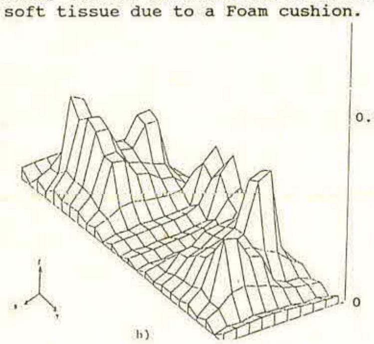

Fig 3.
Shear stress distribution in model soft tissue due to a Air cushion.

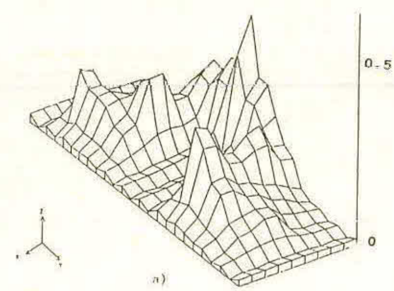

Fig 4.
Shear stress distribution in model soft tissue due to a Gel cushion.

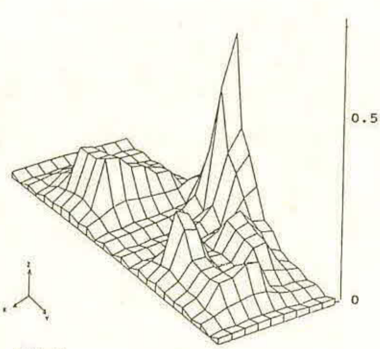

Fig 5.
Shear stress distribution in model soft tissue due to a Wooden base.

Redundant DC-DC Converter for Powered Wheelchairs

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Abstract-**This paper describes the behavior of current flow in the bridge of a motor drive circuit that is given a pulse-width modulated signal. It then presents some of the active and passive techniques to achieve fault tolerance. One of the designs that has been built is explained in detail and some results are presented. Also, a new type of interface unit which can drive the high side nFET is described. This uses the principles of bootstraping.**

I. Introduction

Work has been in progress for a number of years on the development of both improved analog controllers [1] and microprocessor-based controllers [2] for the powered wheelchair. In recent years, the University of Virginia Rehabilitation Engineering Center has been focusing particularly on the development of highly-available and safe microprocessor-based powered wheelchair systems. Results have been obtained on the development of fault-tolerant microprocessor controllers; however, the microprocessor is only one part of the overall system. The microprocessor sends signals to the motor drive circuit. In order to increase the reliability, safety, and availability of the wheelchair, it is necessary to also make the motor drive circuit fault tolerant.

The motor drive circuit may be divided into two parts. One part is the bridge which consists of power MOSFETs that are used to provide bidirectional rotation of the motor and the other part is the interface (or signal conditioning) unit between the microprocessor and the bridge.

II. Non-Redundant Bridge Design

A bidirectional bridge can be built by using a combination of nFETs and pFETs as shown in Figure 1 or by using all nFETs as shown in Figure 2. In order to study the behavior of current flow, consider Q_1 to be driven, Q_2 and Q_3 off, and Q_4 on. When Q_1 is on, a current I_1 is developed through the load and Q_4. When Q_1 turns off, the load current I_2 is commutated to D_2. To provide rotation of the motor in the opposite direction, a similar type of operation could be done on Q_3 with Q_1 and Q_4 off and Q_2 on. A variable drive to Q_1 (Q_3) is most often developed using the pulse-width modulation (PWM) technique.

These switching operations in the bridge may result in a high $\frac{dv}{dt}$ which may result in the failure of the transistors [3]. Also the current required by the motor during the start and under heavy load can be quite high. Thus, it is important to design new methods to make it fault tolerant.

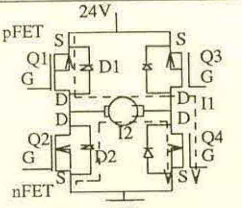

Figure 1. Bridge consisting of nFETs and pFETs

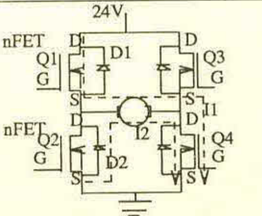

Figure 2. Bridge consisting of only nFETs

III. Design of a Fault-Tolerant Bridge

Different designs using passive and active techniques for achieving fault tolerance have been developed. Passive design uses the concept of fault masking to hide the occurrence of faults. In active technique, fault tolerance is provided by detecting the existence of faults and then switching from the faulty module to the fault-free module. One of the designs which uses passive redundancy is shown in Figure 3. This design can tolerate stuck-on faults (like a short between drain and source or the input of an nFET being stuck-at-1 or the input of a pFET being stuck-at-0) due to the other transistor connected in series in the same module. It can also tolerate stuck-off faults (like an open between drain and source or the input of an nFET being stuck-at-0 or the input of a pFET being stuck-at-1) as the transistors which are connected in parallel in that module can provide an alternate path. This design can also tolerate a number of multiple faults. However, one disadvantage here is the use of a large number of transistors. This is overcome by using some of the active techniques, in which switches are used to shift from one module to the other, once a fault is detected.

IV. Interface Unit

The interface unit required for the two bridges shown in Figures 1 and 2 is different. In both, nFETs in the lower half of the motor require only level shifters. A typical requirement might be a voltage shift from 0 and 5 volts obtained from the microprocessor to 0 and 12 volts to the gate of the lower FETs.

For bridges with pFETs in the upper half, another level shifter is required. Therefore, the interface unit is simple when pFETs are used along with nFETs. However, there are drawbacks in using p-type devices. One of the significant disadvantages is that the on-resistance for a p-channel device is twice that for an n-channel device. Thus, the power dissipation in pFETs would be twice that in nFETs which would result in a lower voltage available across the motor. The problem associated with using nFETs in the upper half of the motor is that as the device turns on, the voltage at its source rises. So, to keep this device on, the gate voltage should also rise

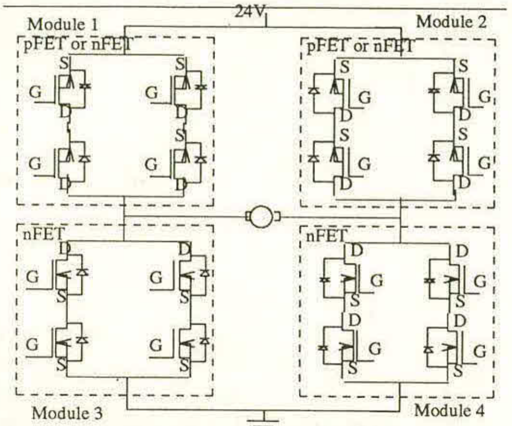

Figure 3. Passive technique using 16 FETs

accordingly, so that a constant gate-source voltage is maintained. One of the ways in which this could be achieved is by using the principles of bootstraping [4] as shown in Figure 4.

A zener diode Z_1 having a breakdown voltage of 12 volts is used. This diode clamps the voltage at A to a maximum of about 36 volts. When the input V_{in} is high, transistors T_1 and Q_2 are on. Thus, the voltage at the gate and at the source of transistor Q_1 is 0. Hence, Q_1 is off and the capacitor C_1 is charged to about 24 volts. When V_{in} goes low, the voltage at B begins to rise and once the gate-source voltage goes above the threshold, Q_1 turns on. Thus, the voltage at point C also begins to rise. The 12-volt zener clamps the voltage at the gate to 36 volts when the voltage at the source is about 24 volts. The charge stored in C_1 is used to maintain a constant V_{GS}=12V.

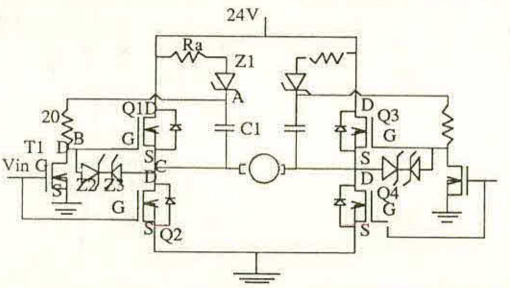

Figure 4. Bootstrap technique to drive high side nFET

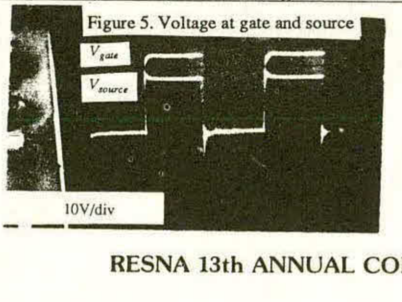

Figure 5. Voltage at gate and source

Using this technique, V_{in} must be regularly brought to a logic "1" to recharge the capacitor C_1. Two zener diodes Z_2 and Z_3 of 20 volts are connected back to back between gate and source as a precaution, to prevent the V_{GS} from exceeding the maximum rating.

V. Results

The bridge circuit shown in Figure 1 was simulated in SPICE to see the behavior of current flow. The motor has been modeled by an inductance L=0.73 mH, and a resistance R=0.13 ohms. To model the back emf, an independent source E is put in series with the resistance.

Another circuit using the bootstrap technique has been built. Figure 5 gives the voltage at the gate and the source of the high side nFET in Figure 4. When the device is off, both the voltages are 0. When it turns on, the voltage at the source rises to 24V while that at the gate rises to 36V. Thus, a difference of 12V is there between gate and source. Figure 6 shows the redundant motor drive circuit that has been built.

VI. Acknowledgements

The authors would like to acknowledge the financial support of the University of Virginia Rehabilitation Engineering Center and the Virginia Center for Innovative Technology.

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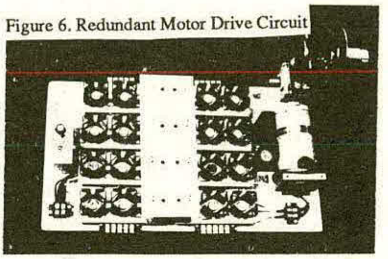

Figure 6. Redundant Motor Drive Circuit

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INNOVATIVE USES OF EXISTING TECHNOLOGY

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Abstract

Foam In Place (FIP) used in the traditional manner may present difficulties in obtaining a precisely contoured seating system in certain circumstances. Adults who are very large and individuals who are affected by high muscle tone are among those who have benefited from a combination of casting techniques and FIP to obtain appropriate contoured seating. Using this technique allows the effects of tone, gravity, and position in space to be assessed prior to finalization of the system. Additionally, the density of the foam can be varied to address pressure/skin considerations.

Introduction

Foam In Place (FIP) is a medium which is commonly used by fabricators to construct contoured seating systems. In our particular setting traditional use of the product, in which foam is poured into a bag placed under/around an individual, does not always result in a successful system for a number of reasons. Individuals with increased muscle tone, sensitivity to heat, and/or who are difficult to position and maintain are among those who require the use of additional technology to make optimal use of FIP technology. Adults who are large sized or very heavy present a challenge because of the necessity of holding them in a precise position for a period of time while the foam is being poured and remains active. Individuals with increased muscle tone or other extraneous movement can, if movement is excessive during certain stages of the process, disrupt the chemical reaction of the foam stopping movement into the desired contours, or can cause hard spots. The process described here details a method that overcomes the aforementioned difficulties and adds substantially more control. Through the use of casting an individual is able to be seated long enough to assess the affects of tone and position in space so that end product is more likely to be appropriate. Additionally, the density of the foam can be varied to address skin/pressure considerations. Modifications can be completed prior to upholstery of the system and fit and suitability can be determined prior to finalizing the system.

Method

This method presupposes knowledge of seating assessment and ability to make a cast using any of a number of systems available on the market. The foam will be poured directly into the back of the cast which serves as a mold for the contoured system.

The first step involves preparation of the cast. The back of the cast should be smoothed by removing rough spots and outside edges with a file/ sanding disc. None of the interior shape of the cast should be altered. If additional surface area on the sides is needed for greater seat width or length plaster strips can be applied to the underside of the cast.

The next step addresses construction of the container for the pouring of the foam. A large cardboard box works well for this process. Measure the length, width, and depth of the cast. Draw lines corresponding to the measurements of the cast. In the center of the box, you should have a rectangle the size of the mold. Continue to finish the container by cutting any excess cardboard and bend up at corners. Tape all corners with duct tape or packaging tape. At this time the container should match the dimensions of the cast. Place the mold in the container and center as well as possible. Make adjustments for angles, rotations, windswept deformities, etc.

Before the foam can be poured into the cast a plastic lining must be applied. Use a large plastic trash bag or a piece of polyethylene sheeting, .004 mil to .006 mil thick. Using spray adhesive (3M 90), apply the plastic sheeting to the cast working from the highest spot toward the outside. Ensure that areas such as the abductor and sides are securely glued and that the plastic is worked into the deepest areas. Wrinkles in the sheeting are normal and can be worked to a minimum. Use the corners to gather excess plastic. Wrap plastic up and over top of the container and attach to the outside of the container. Gather excess folds into the corners nd cover with wide duct tape or masking tape. If large wrinkles on the mold are evident, cover with masking tape to make the seat as smooth as possible. FIP has a tendency to adhere to tape, so coat all taped areas with a silicone based spray. Pam, a cooking preparation, works extremely well for this process.

This presentation utilizes three different densities of FIP to give various combinations of support and pressure relief. Mark the plastic with a magic marker to indicate which density is to go into which area. (More rigid density may be used in side supports and abductor areas with very soft foam used to cushion bony prominences.) Prepare the semi-rigid foam according to MFG data. Partial pours can be used for this process to cut waste to a minimum. Pour FIP around outside of cast and abductor area as indicated. Ensure areas are kept clean where foam is not needed. Gently tip container to allow foam to fill entire outside area if cast is not level, allow the FIP to expand and set per MFG directions. After the foam sets, trim away excess in areas not slated for the semi-rigid density. For best adhesion of foams, remove areas where a skin has formed. Prepare medium foam, pour in mold and allow foam to cure for 15-20 minutes. Again trim areas where the foam has formed a skin. Trim to the level of container if foam rises above the top. Prepare soft density foam and pour in remaining areas. As the foam expands, cover and weight the container. Placing a cover on the top will ensure the FIP is forced into the recessed areas and minimizes air spaces. Careful trimming will help insure the bottom of the piece is flat and fits more easily into the wheelchair. After FIP has cured for approximately 1 hour, disassemble container and remove seat from the mold.

The seat is now ready for final trim and fit. Place the individual in the seat and mark areas to be trimmed. Minor changes, additions, and deletions can be addressed at this time. After the final fit the seat is ready to be upholstered. Upholstery material should be chosen with regard to comfort and water resistant properties. One product, called Rubatex, is a waterproof fabric with 3-way stretch commonly used for skin diving garments. The material may be applied to the foam with spray adhesive.

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Seating Interface for Three Wheeled Scooters

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Introduction

Due to economic and aesthetic reasons we are finding more and more clients wanting to use three wheeled electric scooters. Because these clients needed more postural support we developed a modular seating interface to be used as an adjustable base for custom postural components.

Method

We have found the need for adjustments in seat depth, seat angle, back height, back angle and mounting post. All of these adjustments have been addressed with this seating frame.

The frame is made of stainless steel tubing and consists of five parts; a seat frame, a back frame, two upright connectors with otto bock knuckle joints and connecting posts.

The seat frame is made excessively long to allow for seat depth adjustment. This is accomplished by moving the upright connector back and forth on this part of the seat frame. Once a satisfactory depth is found the upright connector is bolted in place and excessive seat frame is cut off.

The seat frame also contains a series of parallel holes for positioning the connector post. This adjustment allows for proper balance of seating unit. By wedging the seat frame at this point seat angle adjustment is achieved.

The back frame is a clone of the seat frame minus the parallel holes and length. It is also made excessively long and can be cut to the exact height needed.

Because it is made of round tubing traditional drop hook hardware may be used if desired.

The upright connectors consist of slip tube that slides on the seat frame, an otto bock knuckle joint and a slip tube the back frame drops into. This allows the back to be removable for transport.

The knuckle joint allows for back angle adjustment at any time.

The connector post is a clone of whatever comes with the original seat of the three wheeler used. This is welded to a flat plate with holes to match those on the seat frame.

Conclusion:

Due to the flexibility achieved in this seating interface, a therapist can install flat plane, contoured or molded seating components and have the adjustments to achieve proper angles, depths and heights. These adjustments can be changed at any future time if necessary.

This same modular seating interface may be used to retrofit angle in space in a reclining wheel chair or recline in a standard or light weight wheelchair.

Acknowledgements

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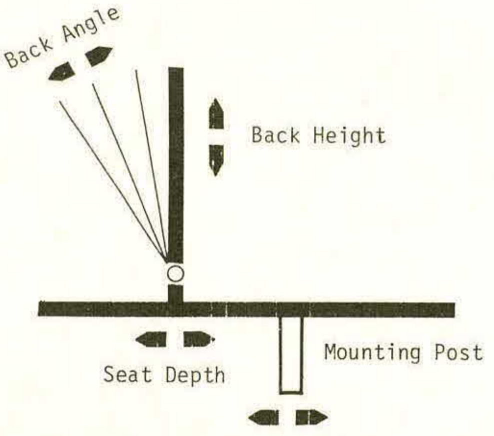
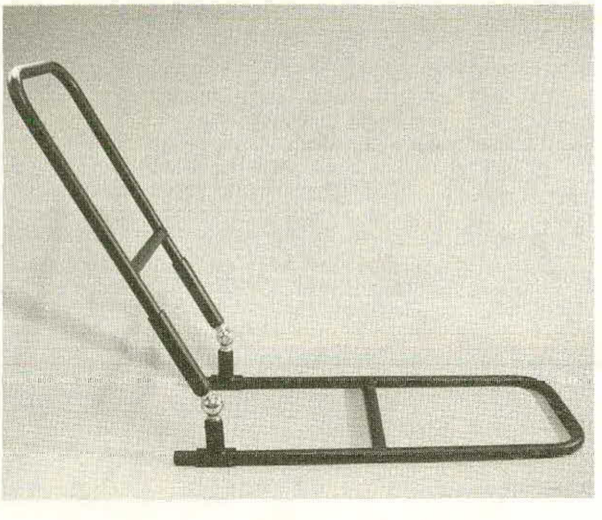


ADJUSTMENTS AVAILABLE



PRESSURE REDUCTION BY PASSIVE STANDING IN THE HIRIDER WHEELCHAIR

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INTRODUCTION:

Prolonged immobilization of the body whether it is due to injury, illness, or other cause has extensive deleterious physiologic and biochemical consequences for practically every major organ and system of the body.

Immobilization has profound effects on the musculoskeletal system, kidneys and urinary tract, respiratory system, cardiovascular system and the digestive system.

Immobilization causes subtle changes in the composition of the skin and is strongly associated with the development of pressure ulcers (decubitus ulcers).

Many times the changes in one system will cause further problematic changes in other systems. The manifestation of these pathological changes is often referred to as the "Immobilization Syndrome" (1).

Tissue ischemia and subsequent breakdown occurs if tissues are exposed to pressures, due to body weight, in excess of the intra-capillary pressure (32 mm Hg) for prolonged periods of time. The normal individual is protected by frequent positional and postural changes which shift the pressure from one area to another. The immobilized patient is unable to make the necessary postural or position changes which shift the pressure, from one area to another. Thus the patient is subjected to high pressures for extended periods of time. The resulting tissue damage inevitably leads to pressure ulcer development.

Passive standing has been demonstrated to prevent, reverse or improve many of the adverse affects of prolonged immobilization. Some of the benefits of passive standing include: prevention or reversal of osteoporosis and resultant hypercalciuria (2,3), prevention of contractures and improvement in joint range of motion (4,5), reduction of spasticity (6), improvement in renal function, drainage of the urinary tract, and reduction in urinary calculi (7,8,9), improvement in circulation, as it relates to orthostatic hypotension and other benefits of good circulation (4,8,9), improvement in bowel function (9) and prevention of pressure ulcers (7,8,10).

The HiRider™ wheelchair is a new powered wheelchair that was designed to provide the disabled user the ability to achieve the standing position.

It is presumed that this powered chair will provide the user with the benefits reported for passive standing. It was the purpose of this study to determine if the assumption of the standing position, as provided by the HiRider chair, would provide significant pressure relief for the HiRider user.

METHODS:

Interface pressures were measured for 20 able bodied and 5 disabled subjects beneath the ischia, trochanters and coccyx in both seated and upright positions as provided by the standing wheelchair.

All interface pressure measurements were made with an electropneumatic pressure sensor (Gaymar PSP-1) on the same wheelchair.

Each subject was initially placed in the seated position. Each bony prominence was located by palpation and the sensor was placed by the investigator. The measurement was recorded and the chair was then moved to the standing position and this measurement was recorded. A total of three such measurements were made at each site with the sensor being repositioned for each set of measurements.

All data were recorded but only the maximum of the three readings was used for statistical analysis. In addition to interface pressure, the subjects height, weight, sex and age were also recorded.

RESULTS:

Preliminary results indicate a reduction in pressure when comparing the seated pressures with the standing pressures. This difference was found to be significant for both able bodied and disabled individuals.

DISCUSSION:

The HiRider wheelchair is a new powered chair that permits the user to transition from the seated to standing position and then back again by activating two switches. The user remains mobile while in either the standing or sitting position.

It has been suggested that **there are many benefits of passive standing and that these benefits may be attained through the use of the HiRider wheelchair. We have begun to study the wheelchair in an attempt to demonstrate whether or not any direct benefits may be documented for this chair. Our first investigation has been concerned specifically with the ability of this chair to provide substantial pressure relief when placed in the standing position.**

We have found that this chair is able to significantly relieve pressure at all measured body sites and for this reason may prove to be a useful benefit for the user of the standing feature of this **particular wheelchair.**

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BIOMECHANICS OF LEVER DRIVE WHEELCHAIR PROPULSION

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ABSTRACT

The biomechanics of lever drive wheelchair propulsion accompanying changes in seat position were investigated. Distinct kinematic differences were noted between subjects and certain similarities were found relating joint position to propulsion kinetics.

INTRODUCTION

To optimize performance in wheel chair propulsion positioning, constr aints and method of interface must coincide with the physical abilities of the user. Previous studies have shown that seat position affects propulsion efficiency and that conv entional handrim wheelchairs are not energy efficient for the user (1,2). Lever drive wheelchair systems offer an alternative method of propulsion (2). This study determined the three-dimensional motion patterns for lever drive propulsion as a function of changes in seat position.

METHODS

Five male wheelchair users between 25-49 years of age were tested in a wheelchair simulator (3). The subjects included 3 paraplegics, one quadriplegic, and a double-amputee. Subjects propelled using a .425 m lever at a simulated speed and load setting of 3 KM/hr and 7.5 Watts per side respectively at six different randomized seat positions. Vertical seat height adjustments were standardized to correspond to 90 and 100 degrees of forearm flexion when the lever was in the vertical position and the seat backrest was aligned directly above the hub axis. Seat movements backward from the hub were in relation to 15 and 20 percent of the subject's total arm length measured from the shoulder joint to the distal end of the third metacarpal of the hand. The 90 and 100 degree seat positions averaged 4 and 6 cm above the hub axis respectively. Seat changes backward averaged 10 and 13 cm for the 15 and 20 percent arm length references.

RESULTS

Push and recovery times averaged 40 and 60 percent of the total cycle time respectively. Total angular displacement of the lever and the point in the stroke where peak hub torque occurred were consistent across seat positions for each subject but differed when compared between subjects. Lever range values were between 38-77 degrees and resulted in a stroke arc of 28-57 cm. Peak torque occurred between 28-59% into the stroke range.

Analyses of the kinematic data generated during the push phase of the cycle showed distinct differences between subjects and variations as seat position changed. Figures 1 and 2 display data for a paraplegic and quadriplegic involved in the study. Absolute values for shoulder movement in flexion and extension for the paraplegic predominated whereas the quadriplegic showed a more evenly distributed movement pattern with elbow motion resulting in the greatest ranges across seat positions. When expressed as a percentage of total arm motion the shoulder motion of the paraplegic made up 50 percent of all movement whereas elbow motion made up 33 percent for the quadriplegic. Both subjects showed considerable upper arm rotation with a decrease in range as the seat was moved back from the hub.

Figure 3 displays the total fore-aft motion of the trunk between the two subjects as a function of seat position. The quadriplegic exhibited greater range across all seat positions in comparison to the paraplegic. This may account for the small upper extremity ranges demonstrated by the quadriplegic as shown in Figure 2.

Figure 1: Joint Ranges for Paraplegic

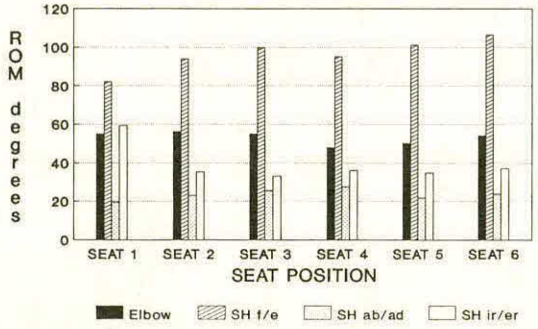


Figure 2: Joint Ranges for Quadriplegic

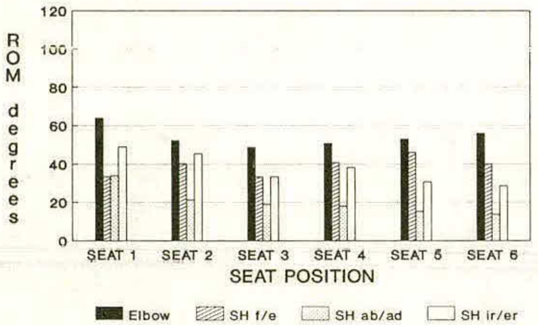
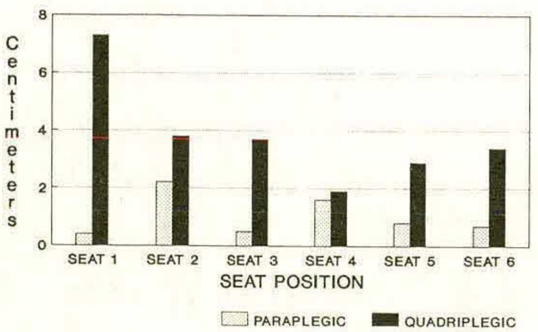


Figure 3: Fore-Aft Trunk Motion



Despite unique differences in motion ranges among subjects joint angle orientation in relation to peak hub torque occurrence remained somewhat consistent even during seat position changes. Peak hub torque occurred when the elbow joint was between 75-100 degrees, the arm was in a relatively maximally abducted position and the shoulder was in slight extension. Further research is needed to understand joint kinetics and how joint positions relate to the generation of peak torque at the wheelchair hub. Comparisons between handrims and levers should also be included in future work.

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A Manufacturing System for Custom Contoured Foam Cushions

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Introduction

Many research and practical methods for prescribing a custom contoured body support system involve an iterative process. Having the cutting or manufacturing process as an integral part of this procedure requires that the process be efficiently and cost effectively implemented. Presently, a CNC based three axis milling machine is dedicated to this task. [1] This machine is capable of contouring an 18x22x3 in. block of material in approximately 20 min. A new cutting machine has been designed and built which has greater capability and is more cost effective. This new machine has a circular cutting region with a radius of 18 in. and a stroke of 8.75 in.

System Configuration

The redesigned cutting machine is controlled by a PC bus based controller. The PC based design has two primary advantages over a stand-alone CNC design: cost and programming flexibility. Closed loop PID control is implemented on each of the three axes with a 32 bit DSP chip. For contouring, a minimum of three degrees of freedom are required. The cutting machine, pictured in fig. 1, has one rotary and two translational joints to satisfy this requirement. This configuration was chosen over the more conventional x-y-z configuration to reduce the cost of building the machine. The three drives are permanent magnet DC servo motors driven by PWM amplifiers. Feedback is provided by incremental optical encoders. The cutting tool is a custom made double edged blade. The spindle drive is an AC synchronous motor driving the spindle at approximately 7000 rpm.

Software Description

User control of the machine is accomplished entirely through software. The input to the cutting system is an array of deflection data representing the contour. The cutting path is generated by fitting quadratic surface elements to the data and extracting the necessary points for the spiral cutting path. Using hardware interupts to communicate between the controller board and the computer, the contour is then carved in the cushion under the direction of the PC microprocessor. The software also provides for manual control of the machine in a jog mode. Jog mode gives the user access to a large subset of the features of the controller via the PC keyboard.

Concluding Remarks

One of the design goals for this system was to minimize cost. Most commercially available positioning systems are designed with error and repeatability tolerances of several orders of magnitude smaller than is required for cutting foam cushions. The task of cutting foam cushions for wheelchair support systems requires an accuracy no greater then ±1 mm. The high accuracy of the commercially available systems increases the cost of these systems tremendously. Designing a custom machine to more relaxed error tolerances greatly reduced the cost of the machine. Using a PC based controller in place of a stand alone CNC controller also reduced the cost.

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ACKNOWLEDGMENT

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Send comments or requests for further information to:

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Charlottesville, VA 22903

Controller:	Superior Electric SPC-703
Sampling Frequency	1 kHz
Input Encoder Frequency	1 MHz
Speed Resolution	8000000:1
PWM Amplifiers:	Aerotech DSHR-80
Peak Output	± 20 A
Continuous Output	± 10 A
Continuous Output Power	765 W
Peak Output Voltage	± 80 V
DC Servo Motors:	Aerotech 1050
Stall Torque	0.35 N-m
Peak Torque	2.52 N-m
Max Speed	6000 rpm

TABLE 1 : SYSTEM SPECIFICATIONS

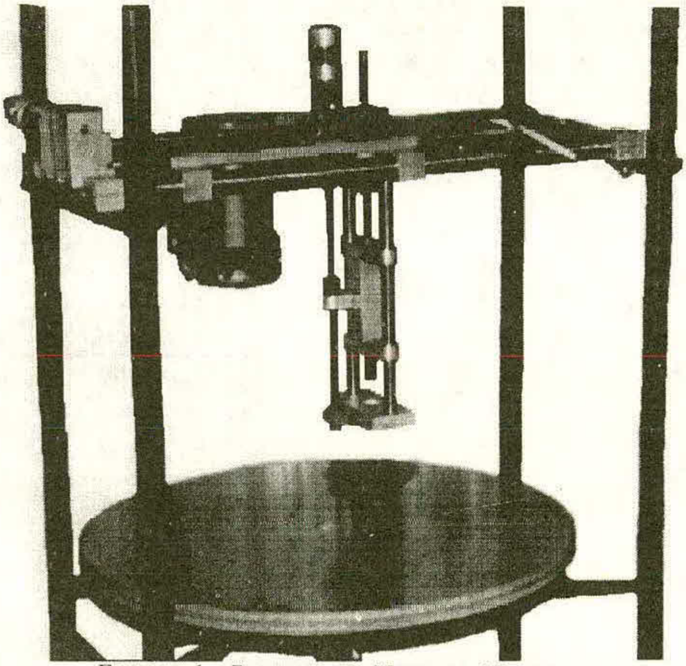

FIGURE 1 : PICTURE OF MILLING MACHINE

FINITE ELEMENT MODEL OF THE HUMAN BUTTOCKS

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INTRODUCTION

Decubitus ulcers are a major concern among people who use wheelchairs. A significant factor in the etiology of these ulcers are the stresses which act on the soft tissue. These stresses occur as the tissue is squeezed between the pelvic bones and the wheelchair cushion. The finite element method can be used to compare the stress distributions caused by different types and shapes of cushions. Thus this technique can be used as a tool in wheelchair seating design.

BACKGROUND

The finite element method consists of three phases: creation of a model, solution of a system of equations, and turning the numerous results into an understandable form. For brevity, only the creation of the finite element model will be discussed here. Experimental verification of the model will be considered in "Experimental Verification of Human Buttocks Model".

PROCEDURE

Creation of a finite element model has several stages: geometry, boundary conditions, loading, and material properties.

Geometry

Once the geometry of the buttocks is determined, nodes and elements will be used to establish the shape that is being analyzed. The geometry of the human buttocks can be determined using Nuclear Magnetic Resonance Imaging (MRI). This process can identify the location and dimensions of various anatomical components of a transverse slice through the buttocks region. An image from a nondisabled male subject is shown in Figure 1. Here the greater trochanter, ischial tuberosities, gluteus musculature, and subcutaneous fat and skin can be seen.

It is not possible to distinguish between subcutaneous fat and skin from the results of the MRI. Since skin is much thinner than the other components of the buttocks, the skin will be modeled as a membrane, 2 mm thick.(1)

By combining several parallel transverse slices, it is possible to create a three-dimensional representation of the buttocks region. A sketch of a two-dimensional model is shown in Figure 2. In this figure, a single buttock is surrounded by a custom contour cushion.

Boundary Conditions

In the finite element process, the structure must always be constrained to create a reference frame against which displacements will be measured. In the model shown in Figure 2, bilateral symmetry is used to simplify the modeling process. The appropriate boundary conditions against horizontal motion will be used along the axis of symmetry. The bottom of the cushion will be constrained from vertical motion. An elastic foundation boundary condition will be placed along the "top" of the soft tissue.

Loading

The model will be loaded by using a percentage of the subject's body weight acting vertically downward on the top of the ischial tuberosity. In the supine position, 6.7 percent of a male subject's weight is supported by the cushion. In the seated position, 28.9 percent of a male subject's weight is supported by the cushion.(2)

Material Properties

In the biomechanics literature, biological tissue is described as being a non-linear, anisotropic, viscoelastic material.(3) Due to the large differences between the material properties of bone and the other tissues in the body, the bone will be modeled as a linear, isotropic, elastic material. The goal of this research is to create a non-linear, viscoelastic model of the tissues in the buttocks. At this stage, the materials are treated as linear, elastic substances.

Numerous studies have been made of the properties of skin and bone, such as those by Cargill(4) and Fung(3), respectively. In the model, material properties for these tissues are based on those found in the literature. On the other hand, very little work has been done to determine the compressive properties of gluteal muscle and subcutaneous fat in humans in the <u>in vivo</u> case. These properties were determined experimentally.

Using a seating contour gage, a force-deflection relationship for these tissues in uniaxial compression was determined.(5) The experimental results for a supine, nondisabled male are shown in Figure 3. Initially the relationship is linear. After a force of 7.0 N is reached, an exponential effect can be seen. Young's modulus of elasticity and Poisson's ratio can be determined using a method which is beyond the scope of this paper. The interested reader can find the appropriate equations in Timoshenko and Goodier.(6) The linear material properties being used at this point in time are shown in Table 1.

CONCLUSIONS

The finite element model of the human buttocks described in this paper will be the basis for a design tool for improving wheelchair seating systems. Results from this basic linear elastic plane strain model show a deflection under the ischial tuberosity of 0.4 mm. While this deflection appears to be somewhat small, changing Poisson's ratio of the cushion to 0.2 and the soft tissue to 0.3 leads to a deflection of 3.6 mm. This change appears to offset some of the overconstraint in the plane strain condition. Further refinements of the model, including expansion to three dimensions and additional work with the material properties should result in a more accurate description of the displacements and stresses in the human buttocks. Experimental verification of the model will be discussed in "Experimental Verification of Human Buttocks Model".

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ACKNOWLEDGMENTS

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Beth A. Todd, University of Virginia Rehabilitation Engineering Center, Box 3368, University Station, Charlottesville, VA 22903.

TABLE 1
MATERIAL PROPERTIES OF HUMAN TISSUE

Tissue	Elastic Modulus(Pa)	Poisson's Ratio
bone	$17.0X10^9$	0.31
muscle/fat	$14.0X10^3$	0.49
skin	$50.0X10^3$	0.3

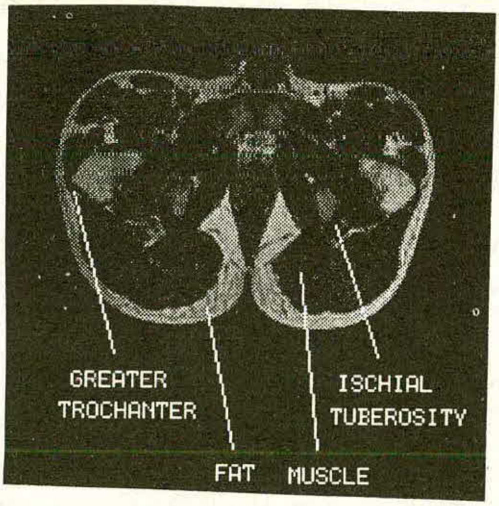

Figure 1. Transverse section of free-hanging buttocks generated with MRI.

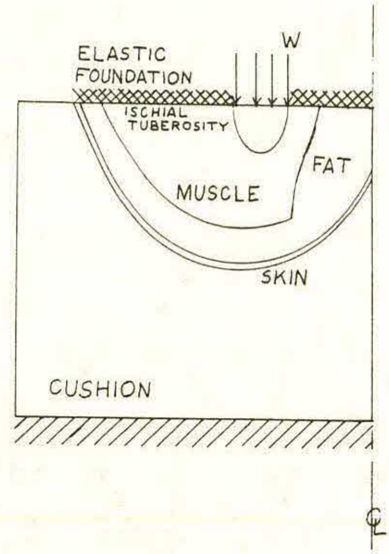

Figure 2. Sketch of two-dimensional model.

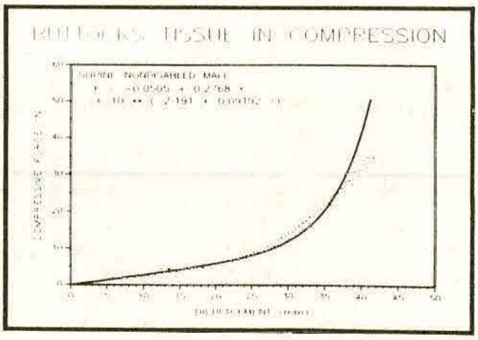

Figure 3. Nonlinear material relationship for nondisabled male.

A CASTER SHIMMY DAMPER DESIGN

James J. Kauzlarich, Edward V. Mochel & John G. Thacker
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Introduction

When a caster wheel goes into shimmy, the drag on that wheel can be so high that the wheelchair will be forced to one side or even turn over. Caster shimmy is a self-excited vibration which occurs above a critical speed of the wheelchair, and the equations for this phenomenon have been published (Kauzlarich, et al.). A study of caster shimmy (Mochel) found that a hydraulic damper or a friction washer are effective in suppressing shimmy. The design of a maintenance free, friction washer shimmy damper is considered in this paper.

Design

The spring-washer shimmy damper is shown in Fig. 1. The washer is made of brass with a key which fits the keyway cut into the caster stem, and the washer rubs against the outer race of the upper bearing, Part 1. A stainless steel spring producing the proper frictional torque on the brass washer is shown as Part 2. A steel washer, Part 3, seated on the inner race of the lower bearing supports the spring.

Design Parameters

In the design of the damper, the important variables (Ref. 1) are caster wheel moment of inertia (I_w) about the wheel diameter axis, trail (T), lower limit of shimmy velocity (V_c), caster stem bearings plus damper friction torque or moment (M_f), and level of random deflections (Θ_o) encountered by the caster wheel as it travels along the road.

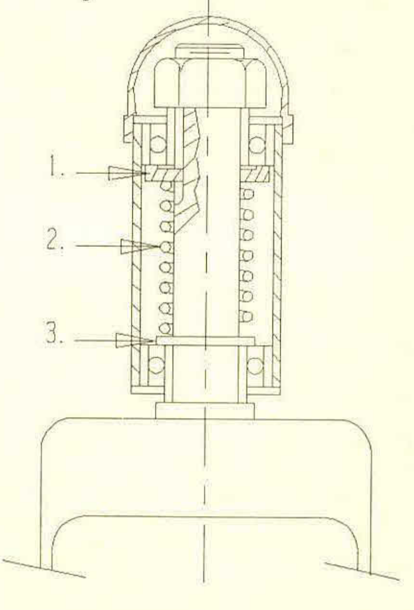
The governing equation for caster shimmy (Ref. 1, Eq. 7) with no tire groove (B=0), for predicting the friction torque is

$$M_f = \frac{(\pi/4)V_c^2 \Theta_o I_w}{T^2} \qquad [1]$$

Selecting an 8 inch Everest & Jennings caster wheel for modification, the required frictional torque as a function of shimmy critical velocity is shown in Fig. 2. The E&J 8"x7/8" wheel was tested in a caster fork with only stem ball bearings providing frictional damping (Ref. 1, Fig. 14). Using the parameters listed in Fig. 2, for a V_c=1.58 m/s (Ref. 1, Table 1) gives a value of M_f=0.199 N-m for the stem bearings. If it is desired to have a V_c=3 m/s (6.7 mph), then the additional frictional torque needed is M_f=0.612-0.199= 0.413 N-m (3.65 #-in.). In Ref. 3, it was found that random deflections of the caster wheel while running on a treadmill varied from about 5° to 10°. As the greatest deflection, Θ_o=10° is chosen for analysis.

A material with a high dynamic coefficient of friction should be selected for Part 1 to keep the spring force low. The material should have a similar static

Fig. 1 CASTER SHIMMY DAMPER



coefficient of friction to avoid a high starting torque and stick slip while operating. Aluminum on aluminum was tested in Ref. 3 with satisfactory results, but brass on steel is selected for this design as being structurally superior with a much lower wear rate. The brass-steel dynamic coefficient of friction (dry) is μ=0.44 and the static μ is 15% higher. The stem bearings should be sealed for weatherproofing and so no lubricant gets on the shimmy damper.

The spring, Part 2, is required to develop a spring force at the brass washer according to the equation

$$F_s = \frac{M_f}{\mu R} \qquad [2]$$

where R is the radius to the contact between the brass washer and the outer race of the upper bearing. Substituting R=0.011 m (7/16") and M_f and μ into [2], gives F_s=85.3 N (19 #). If the rubbing contact takes place over a large area, then Eq. [2] becomes (Ref. 4)

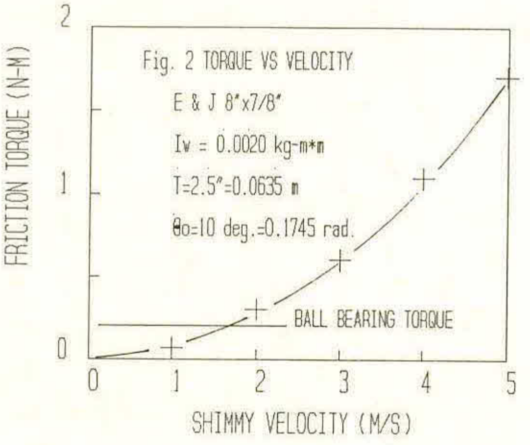
$$F_s = \frac{M_f}{(1/2)\mu(R_o+R_i)} \qquad [3]$$

A stainless steel (AISI 302) spring was designed for this problem (Mott), and has the following design parameters.

14 Gage wire (D_w=0.08 in.)
spring constant, k=19 #/in.
mean diameter, D_m=0.75 in.
free length, L_f=2 in.
number of coils =6.46+2inactive
solid length, L_s=0.676 in.
stress @ L_s, τ=107.2 ksi

Discussion

The test results (Mochel) have shown that the friction washer damper is an inexpensive and maintenance free method of providing frictional torque to the caster stem, thereby suppressing shimmy. The additional effort required for turning the wheelchair is not expected to be apparent to the user. The latter observation was found for the conical wedge damper using a higher frictional torque (McLaurin).



Acknowledgement

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AN ALTERNATIVE METHOD FOR PRODUCING CUSTOM CONTOURED SEAT AND BACK CUSHIONS USING LIQUID FOAM IN PLACE TECHNOLOGY

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ABSTRACT

An alternate method of applying liquid foam in place technology in the production of custom contoured seat and back cushions has been developed. The liquid foam is poured into a negative cast taken from a positive simulator mold, as opposed to the standard method of pouring into a plastic bag. Several advantages are apparent with the new method, including increased positional control, ease in achieving deep and supportive contours, and improved aesthetics.

INTRODUCTION

Custom contoured seating systems are a viable and necessary means of positioning handicapped individuals with severe musculoskeletal deformity. One widely used method of producing custom contoured seat and back cushions is the liquid foam in place (FIP) system (1).

The most common method of applying the FIP system is to pour the liquid foam into plastic bags which are placed underneath or behind the patient depending on the component being molded. The plastic bag method has several significant drawbacks, including difficulty in maintaining patient position when strong uncontrollable reflex patterns exist, and problems in achieving the deep contours which are necessary to accommodate and support severe hip, pelvis, and spinal deformity.

An alternate method of incorporating the FIP system has been developed. This method involves producing a negative plaster cast of the patients body shape from a simulation molding frame, followed by pouring of the liquid FIP kits into the plaster cast to produce positive seat and back cushions.

METHODS/MATERIALS

The patient is initially transferred into a simulation frame which incorporates vacuum consolidation techniques to allow hand formation of custom seat and back molds (2). He/she is removed from the simulator once the molding process is complete, and the desired positioning is achieved.

The resulting positive mold of the patients body can now be modified as necessary, and then covered over entirely with plaster splinting material to produce a negative body mold. When laying the plaster over the mold, it is important to allow the splint to drape all the way down the sides of the seat and back molds, and to touch the solid base below and behind. This provides flat and parallel surfaces on the back and bottom edges of the negative mold. These perfectly aligned surfaces provide for proper seat to back alignment during later stages of cushion fabrication and mounting.

When the negative plaster cast has dried sufficiently (1-2 days), it can be prepared for the pouring of the liquid FIP kits. Preparation consists of trimming away excess splint, filling small gaps with moldable putty, and then coating the inside surface with a release agent to allow easy removal of the foam cushions.

Several products were tested as release agents, with varying degrees of success/failure. After experimentation it was decided that Crisco Vegetable Shortening was the simplest most effective solution.

The actual cushion fabrication process consists of pouring mixed liquid FIP kits into the negative plaster cast one at a time until the mold is filled. Plastic sheets are held in place against the bottom and back edges of the cast to control cushion thickness, and to allow flat posterior/inferior cushion surfaces for orientation and mounting. The flat and parallel surfaces formed on the back and bottom edges of the cast during the splinting process assure that proper cushion orientation in the various body planes is maintained throughout the pouring process and into the final product.

The cushion is removed from the cast, trimmed to suit, and then upholstered when the pouring process is complete. Upholstery consists of either vacuum formed vinyl or dipping in a resilient, waterproof solution by the Danmar company (3).

An additional technical concern arises when a gel insert (4) is incorporated into the FIP cushion for improved pressure distribution and anti-shear capabilities; velcro strips need to be attached to the vinyl or Danmar cover for holding the gel insert in place. The best method found to date is to sew vinyl, face out, to the back side of the velcro. Loctite Super Bonder # 414 glue (5) is then used to achieve a vinyl to vinyl, or vinyl to Danmar bond. The bond in either case is chemical, and is very strong.

DISCUSSION

Producing FIP custom contoured seat and back cushions from a cast which has been taken from a simulation frame mold has proved to be advantageous over the plastic bag method in several ways. The simulation frame molding process is a much more controlled method when working with a patient who has very strong and uncontrollable reflex patterns, as opposed to manually trying to hold the patient in place while the liquid foam rises in a bag. Deep and supportive contours are much more easily and accurately achieved when working with a patient who has severe hip, pelvis and/or spinal deformity. Finally, from an aesthetics point of view, FIP cushions produced from a cast have a much smoother and more wrinkle free surface.

This method of producing custom contoured seat and back cushions is but one of several methods available at this time, all of which have advantages and disadvantages. Additionally, research and development is ongoing at several centers with regards to CAD/CAM techniques for producing cushions. This technology is very promising as an alternative to FIP techniques and may further contribute towards improving fit, delivery time, and aesthetics of custom contoured cushions.

SUPPLIERS

1. Dynamic Systems Inc.
   Rt. 2, Box 182B
   Leicester, N.C. 28748

2 Pin Dot Products
   6001 Gross Point Rd.
   Niles, IL 60648

3 Danmar Products
   221 Jackson Industrial Dr.
   Ann Arbor, MI 48103

4 Jay Medical
   P.O. Box 18656
   Boulder, CO 80308-8656

5. Loctite Corporation
   Newington, CT 06111

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THE CENTER FOR SPECIAL EDUCATION TECHNOLOGY

Susan Elting, Elizabeth Lahm, and Nancy Meidenbauer
Department of Communication
The Council for Exceptional Children

ABSTRACT

The Center for Special Education Technology at the Council for Exceptional Children is a national information center funded by the U.S. Department of Education, Office of Special Education Programs. The Center's mission is to influence the quality, availability, and use of technology in special education through the increased use of information. To that end the Center provides a range of information products and services for educators, researchers, developers, and publishers. Through its active participation and development of vital information products, the Center has become a national leader in the area of special education technology.

BACKGROUND

Since the early 1980's, the U.S. Department of Education, Office of Special Education Programs (OSEP) has had an ongoing commitment to the systematic development and application of technology advances in the education of children and youth with disabilities. To meet the continuing information requirements of those who develop, produce, and use technology in the education of handicapped children, the Department has funded a sequence of special education information exchange projects beginning in 1981. The Center for Special Education Technology was established at CEC in 1984 to provide a linkage for the effective flow of information from research and development to application. In fiscal year 1987, CEC was awarded a four-year contract to continue operation of the national information center through 1991.

CENTER SERVICES

As a national resource with the goal of increased use of information about technology in the education of children with disabilities, the Center monitors information needs in the field and collects and synthesizes information spanning the technology, disability, and education fields. The provision of theme-related services is a central strategy for the Center. Information collection and synthesis activities focus on selected substantive topics or themes where gaps in the organization of the knowledge base are addressed.

To meet the continuing need for general awareness information about the use of technology and alternate resources in the field, the Center provides ongoing general information services. In addition the Center conducts two meetings each year. One focuses on the use of technology in the schools with practitioners as the primary audience and the other focuses on research and development in the area of technology with researchers and developers as the primary audience.

<u>General Information Services</u>. The Center develops a variety of information products highlighting trends, resources, practices, and research efforts in the field. Products are distributed to service providers (such as education agencies, professional associations, and universities) and to product providers (such as researchers, developers and publishers). Current general information products include the following:

State and topical <u>Resource Inventories</u> listing local, state, and national technology resources that provide information and services for professionals and consumers.

A <u>Tech Use Guide</u> series summarizing issues and applications in technology use such as Computer Access, Selecting Software, Technology and Learning Disabilities, Technology for Preschool Children, and Technology for Children with Visual Impairments.

The Marketplace is a periodic publication highlighting vital marketing issues affecting special education technology. It is aimed at publishers and developers of technology products.

TECH.LINE is the Center's electronic newsletter on SpecialNet which provides current and topical information to special education professionals and education agencies.

Theme-Related Services. A major component of the Center's services is its indepth focus on identified themes in special education technology. Theme activities address expressed information gaps by identifying existing knowledge and organizing that knowledge in various product formats. To date, three information themes have received Center attention: assistive technology, funding of technology equipment and programs, and technology training for practitioners.

The Center's efforts in assistive technology focused on three aspects of use: products and their availability, service delivery strategies, and integration of assistive technology within the educational/learning environment. In the area of funding, information products emphasize increasing awareness of funding sources and strategies for securing funding of technology products as well as practices and programs for the long-range acquisition of technology in educational settings. The technology training theme emphasizes the infusion of technology in the process, content, and products of preservice and inservice training.

SUMMARY

The Center's information products are targeted for service providers and product providers active in the use of technology in special education. These audiences in turn provide information and support to the technology consumers -- educators, parents, and individuals with disabilities -- who ultimately apply the technology in living and learning. The Center's products are in the public domain and are routinely made available to representatives of target groups and to individuals on request.

ACKNOWLEDGEMENTS

The project is funded by the Office of Special Education Programs, U.S. Department of Education under Contract No. 300-87-0115 and operated by The Council for Exceptional Children. For more information, contact the Center for Special Education Technology, CEC, 1920 Association Drive, Reston, VA 22091 or call 1-800-873-8255.

REVIEW OF THE NEEDS OF PHYSICALLY HANDICAPPED PERSONS IN THE VOCATIONAL COUNSELING PROCESS AND A POSSIBLE SOLUTION

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INTRODUCTION

This paper will describe the results of a study and literature review concerning the specialized needs of physically handicapped persons in the vocational counseling process; a concept that was developed to address these needs; and a computer software program based on that concept that is now available to help address these needs.

BACKGROUND/LITERATURE REVIEW

In 1979, the National Occupational Information Coordinating Committee (NOICC) funded a study through the Florida Occupational Information Coordinating Committee and the Florida Association of Rehabilitation Facilities to examine the special needs of physically handicapped individuals in the vocational counseling process. NOICC has been responsible for assisting states to develop and make available a broad range of career information. Private companies are also offering computerized and hard copy systems that allow an individual to select careers based on their interests, educational level, desired income, etc. NOICC's interest, however, in 1979, was to examine the special vocational needs of persons with physical disabilities.

This one year study and literature review resulted in the following conclusions: persons with physical disabilities have a need for 1.) occupational information which includes detailed and accurate data on the physical requirements of jobs; 2.) a method to obtain detailed information about the physical capacities of the individual; 3.) a systematic and comprehensive way to compare the physical capacities of the individual with the physical requirements of occupations of interest; 4.) and lastly, a method to consider assistive devices information if there is a discrepancy between what the individual can do and what the occupation requires (Seigel et al., 1980). This study found that these needs are not met in existing vocational information resources because they use either the disability method or the rating method to compare an individual`s physical capacities to the physical requirements of occupations (Seigel et al., 1980). In the disability method, disabled people are classified into various disability groups such as the spinal-cord injured, the visually impaired, and so on (Hanman, 1958). An individual with a particular disability reviews only those occupations feasible for persons with that disability. Using this method can overly restrict and stereotype persons with physical disabilities. This approach also fails to take into account the differences between people. Persons with the same physical disability can differ widely in their capacity to perform the physical demands of occupations.

In the rating method, an individual`s physical capacities are compared to the physical demands of jobs using general or aggregate terms like "light" lifting (Hanman, 1958). Many existing systems use this approach. The use of these general or aggregate terms makes it difficult to determine the feasibility of occupations of interest. Using the computer further exacerbates this problem in that entering data like "light" lifting can automatically eliminate a large number of occupations, many of which the individual could potentially do. The computer can very rapidly reduce an individual's choices using this aggregate approach.

DEVELOPMENT OF ISABEL

ISABEL (as in is-able) is a software package that attempts to address the needs identified in the NOICC study. It is a revised and updated version of the Job Related Physical Capacities system originally made available by the Florida Association of Rehabilitation Facilities (F.A.R.F.) (Morgenthau, Ranson, Stevens & deMarsh-Mathues, 1984).

THE ISABEL APPROACH

The ISABEL system uses a step-by-step approach to assist the individual with a physical disability to determine the feasibility of occupations of interest. The system uses ninety-five (95)+ physical and environmental factors to describe both the occupation and the career seeker. These factors represent a detailed extension of the physical and environmental factors used in the Dictionary of Occupational Titles (Peterson & Buchanan, 1985). The system compares the individual's profile to occupations of interest and reports possible discrepancies between the job requirements and the individual`s physical capacities.

CONCLUSION

ISABEL is a software package that was developed to resolve some of the needs physically handicapped individuals have in the career exploration process. The system includes detailed physical demands data, a method to compare a counselee to the physical demands of an occupation, and a systematic approach to searching for assistive devices. The system is potentially useful in the career exploration, vocational evaluation, and job placement processes and in the provision of vocational training and expert testimony.

For further information on ISABEL contact The Magellan Corporation, P.O. Box 10405, Tallahassee, Florida, 32302 or call 904/422-2752.

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Easter Seal Student Design Competition

Easter Seal Student Design Competition

RESNA and National Easter Seal Society (NESS) have enjoyed another exciting student design competition! The 1990 judging panel had the difficult task of reviewing many excellent design projects and choosing five winning entries. As members of the judging panel, we were impressed with the creativity and insight applied to solve real-life problems using both high and low technology. Fresh approaches, highlighted with creative flair, focused on some age-old problems such as seating for older persons and a transportable seating system for third world disabled children. One project focused on designing an inexpensive, portable, remote control door opener. Another group of students brought the positive attributes of horseback riding to physically involved equestrians through the use of a very practical trunk stabilizer which attaches to a saddle. As technology development continues to soar we have experienced new challenges, as demonstrated by the project addressing the need for a computer joystick interface and software that adapts to hand tremors. A common thread to the winning entries, in addition to a sound design approach, was the involvement of people who ultimately will benefit from these innovative designs. The consumer was a key member of our winning Easter Seal student design project teams.

NESS and RESNA applaud the efforts of all the students who devoted considerable time and thought to this year's competition. The five winning projects will be provided transportation and housing at the RESNA 13th Annual Conference in Washington, D.C. There will be an opportunity for the students to exhibit and present their exciting projects as well as attend other presentations, exhibits, and workshops to broaden their knowledge of how technology is being applied to help others.

RESNA is grateful to the NESS for their continuing support of this most worthwhile event. We also thank members of the judging panel for their time and effort in selecting the five finalists. And to Susan Leone a big thanks for sending out the notices, receiving the applications and project entries, notifying the winning student teams, and arranging flights and accommodations at the conference, we couldn't do it without you!

Ken Kozole, BSME, OTR
Chair, Easter Seal Student Design Competition

James L Mueller
Local Chair, 1990 Easter Seal Student Design Competition

Design of an Inexpensive, Portable, Remote-Controlled Door Opener

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ABSTRACT

A safe, inexpensive, remote-controlled door opener for use on the entry door of a house or apartment was designed and built. This device addresses the needs of electric wheelchair riders and other people whose mobility is restricted. Many in this target group have limited budgets; thus, a primary concern was to minimize both the purchase costs and the installation costs of the device.

Our prototype device retracts the deadbolt and main latch and opens a sidehung door. It is powered by a small electric air compressor, which is controlled by a single-button remote transmitter.

BACKGROUND

The need for an inexpensive automatic door opener is shared by a wide range of people with disabilities. Our "model" user is an electric wheelchair rider who would enjoy greater personal independence by being able to manage his or her entry door without assistance. But our potential market includes anyone for whom a common sidehung door is a formidable barrier, such as some push wheelchair riders, people who walk with mechanical aids, and people who need or prefer to open their door for a guest or attendant without leaving a bed or chair. In the latter case, the door opener would be valuable for security, as users would no longer need to give entry door keys to all attendants and visitors.

Automatic door openers on the market today are expensive to purchase and require professional installation. To accommodate a locking entry door, the additional purchase and installation of an electric strike plate is needed. If the door has a deadbolt, that calls for a second electric strike plate. Such an installation requires a carpenter to cut into the door jamb and an electrician to hard wire the strike plate and door swing mechanism. These expenses will be incurred again if a user, who is typically renting his or her residence, moves to a new location.

DESIGN OBJECTIVE AND CRITERIA

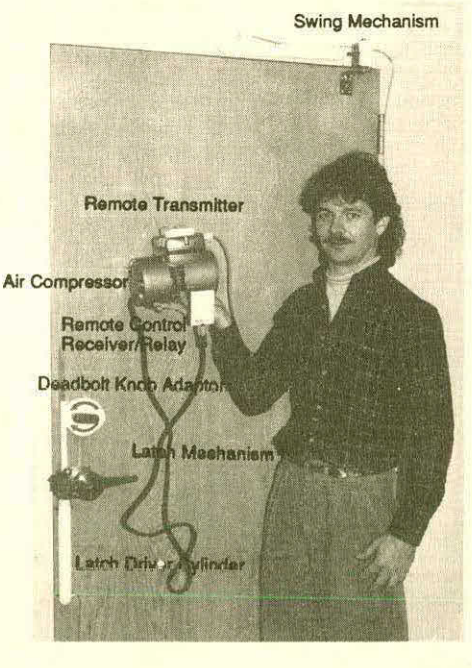
Our objective was to design, build and test a prototype device for the remote-controlled opening and closing of an entry door.

<u>Design Criteria</u>
The device should:

1. Unlock and open, then close and lock a sidehung entry door with a main latch and deadbolt in response to a remote signal.
2. Retail for $500 or less (this was chosen as roughly half the purchase price of presently available automatic powered door openers, none of which include latch/unlatch mechanisms).
3. Be completely portable (to enhance long-term usefulness and fundability, as discussed above).
4. Be easily, non-destructively installed by a person with average home repair skills (to minimize installation costs).
5. Be easily adapted to a variety of doors (to minimize installation costs and broaden the potential market).
6. Not interfere with the normal manual operation of the door (this allows housemates and guests to use the door without employing the remote transmitter; and ensures that the door can be operated any time the automatic system becomes disabled, such as during a power failure, even in the midst of the device's opening or closing sequence).
7. Have safety override to disable the system if the swinging door encounters an obstacle.

DESCRIPTION OF THE DEVICE

The system uses compressed air as the energy conversion medium to produce rotational motion (of the deadbolt and main latch knobs, and of the door about its hinges) from electrical energy (115 Volt AC power source).



A remote-actuated relay switch controls a 1/10 horsepower electric air compressor. The air pressure moves the pistons in two inexpensive linear actuators; one actuator drives the door open and the other causes the main latch (ML) and deadbolt (DB) knobs to turn.

The necessary sequencing of events, such as retracting the deadbolt before opening the door, is accomplished by utilizing the natural variation in system air pressure with time. When the compressor is switched on, system pressure rises from 0 to 35 pounds per square inch gage (psig). As it does so, different events take place at different pressures, and therefore at different times. Although door closing is spring-driven, events are still sequenced by system air pressure as it decays from 35 back to 0 psig.

The system gracefully handles interruptions to its usual cycle, such as when the door swing is obstructed, or when a manual door user leaves the closed door unlocked.

Portability
Professional installation is a significant cost that we decided to minimize or eliminate by design. Installation of our device requires only average home repair skills, and is not permanent or destructive. The resulting portability of the device should eventually help it to qualify for funding as Durable Medical Equipment.

Safety
One of the strengths of our design is in the important area of user safety. The device is inherently safe because the forces it is capable of exerting are minimal. On our test setup, for example, we experienced a maximum steady opening force of 8 lbf at the edge of the door when blocked by an obstacle, and 4 lbf during closing. (Inertial forces will depend upon the door weight and opening/closing speed adjustments.) The opening force will not exceed this maximum because the diaphragm compressor is not capable of raising system pressure beyond 40 psig.

Safety is also enhanced by the transparency of the device to manual operation. In the event of a power failure, for example, a manual user only needs to overcome 4 lbf resistance to opening. ANSI allows 40 lbf (ANSI 1985). Future work will include exploration of power backup systems.

DESIGN PATH

This project began at SFSU over four years ago when a physical therapist at a local Independent Living Center brought the need for a door opening aid to our attention. In the spring of 1989, a student team worked on refining the design of a system that would employ a garage door opener as the heart of the system. But a breakthrough came in the fall of 1989 when a member of our team, Mr. Jon Eccleston, introduced an alternative idea: designing a system using compressed air (C/A) as the power medium. We decided that C/A was the more promising choice in nearly all respects, including:

- safety
- design flexibility (for design of latch/unlatch mechanisms)
- design transparency (lack of impact upon normal manual door operation)
- aesthetics, including noise level.

The team's major work became the development of the latch/unlatch mechanism. This included the system of sequencing discrete latch and swing events, and the mechanical linkages that allow transparency of the device to manual operation.

CONCLUSIONS

There is a need for an inexpensive automatic door opener that can manage both locking and swinging functions of a home entry door. We believe that our succesful prototype proves the validity of the design concepts used. It is worthwhile to continue refining the design toward eventual commercial production.

ACKNOWLEDGMENTS

The authors wish to thank Dan D.Wilson of the SFSU Engineering Design Center, and Peter Pfaelzer and Ralf Hotchkiss of the SFSU Rehabilitation Engineering Technology Training Project staff, for their guidance and support.

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A BLACKBOARD KNOWLEDGE-BASED APPROACH TOWARDS IMPLEMENTING AN ADAPTIVE FORCE JOYSTICK COMPUTER INPUT DEVICE FOR PERSONS WITH TREMOR DISABILITY

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ABSTRACT

This paper describes an experiment in computer-human interaction aimed towards the development of an adaptive computer interface for disabled computer users. The scope of the experiment is limited to a force joystick, and to users exhibiting intention tremor. The design of the interface, the experiment used to test and refine the software, pilot study results, and the result of an initial experiment using the interface, are discussed.

INTRODUCTION

The goal of this research is to develop an adaptive computer interface, henceforth referred to as an *operation assistant* (OA), for persons who experience motor disabilities. This type of interface is one where the computer models the activity of the user and in turn uses the model for guidance in making adjustments to interface parameters. This is done to maintain the "quality" of the computer-human interaction. Many computer users are extremely adaptable and can usually (grudgingly) adapt to a wide range of anomalies in the interface, however persons with motor disability may not be able to adapt; they may require an OA to perform the adaptive functions. For these persons, the day-to-day variability in the musculoskeletal control of their limbs may necessitate constant adjustments to the interface parameters.

The prospect of an OA running in the user interface concurrently with commercial applications will become a reality on computers which will become available in the next few years. The challenge will reside in performing the adaptations in a supportive, smooth manner. For disabled users, an OA continually monitoring the computer-human interaction could result in a considerable improvement in productivity. At this time however experiments designed towards developing the OA may involve using a separate computer to run the OA software.

There are a considerable number of possible parameters which can be adjusted in an OA[1], just as there are many different types of motor impairments which can occur. Here, a single aspect of the OA was isolated for study and experimentation --- the input device. All other factors in the interface were held fixed. Subjects selected for study were persons with Friedreich's ataxia, who are characterized at the motor level by athetosis and/or tremor of the limbs. A force joystick was chosen as the input device since it provides a solid anchor point and relevant variables can be implemented purely in software.

The statistical properties of the tremor and athetosis can change significantly from day-to-day for persons with Friedreich's ataxia. The adaptive action of the prototype interface is to model the user's manipulation of the joystick, characterize the tremor, and select the appropriate gain of a simple linear velocity control filter for the joystick to dampen out unwanted movements. The system also explains why any changes have been made. In order to perform this adaptive function, the interface software must make use of all available information. This information consists of: (1) verbal reports from the user and therapists who have observed him/her; (2) numerical information collected from the force joystick and cursor movement on the computer screen, and (3) information coming from a knowledge-base of expertise stored in the form of frames and rules.

OPERATION ASSISTANT FRAMEWORK

Improving tracking performance implicitly involves answering the question: what is meant by 'good' tracking? This problem can be addressed using various techniques and all have strengths and weaknesses. Examples include: (1) qualitative assessments made by a therapist observing the action; (2) tracking indicators such as rise time, overshoot, targets missed, and others; (3) nonparametric modelling of the user's transfer function achieved via spectral anlysis of the user's cursor movement; and (4) parametric models of the user's cursor movement such as auto-regressive moving average (ARMA) models. An experimental operation assistant which utilizes all of these techniques together may provide the best possible joystick gain estimates.

A blackboard knowledge-based expert/control system approach was used to organize the tracking assessment techniques and is described in detail elsewhere[2]. Figure 1 depicts a simplified block diagram of the author's implementation of a blackboard system. The present implementation of the system uses two blackboards. The control blackboard coordinates all system control activities. The domain blackboard coordinates the building of a user model and is used to determine filter changes in response to user performance changes. Each blackboard consists of several levels ordered with respect to the level of abstraction in the representation of the information. In lower levels units of information are more numerical in nature whereas at higher levels the representation is symbolic and linguistic.

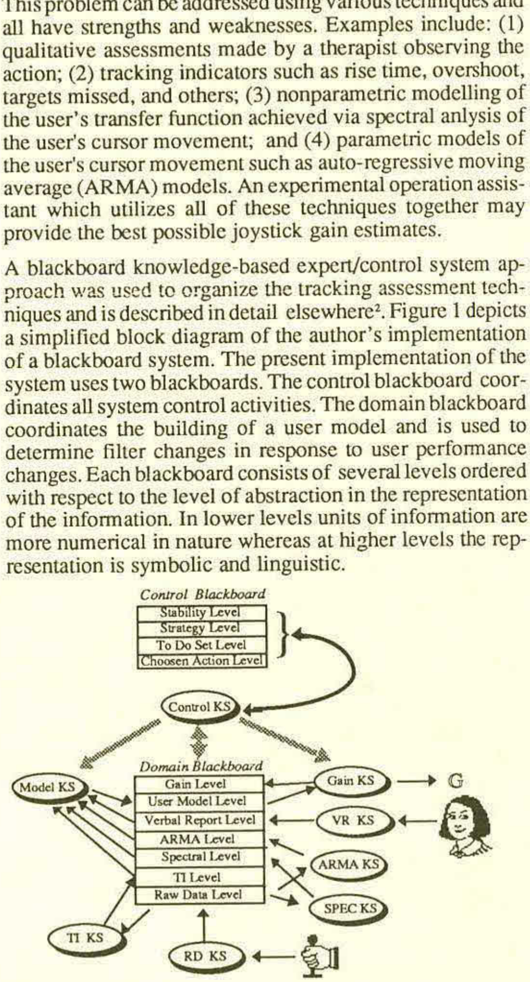

Figure 1: The blackboard framework for the operation assistant.

The domain blackboard consists of 7 levels each maintained by a corresponding knowledge source(KS): (1) The raw data level is comprised of a storage area for raw force, cursor position, and time data coming in from the joystick. The maintenance of this level is the responsibility of the raw data KS; (2) the tracking indicators (TI) KS operates on the raw data to derive various tracking ability indicators such as rise time, overshoot, targets missed. cursor speed and others.

The results are kept at the TI level; (3) the spectral KS employs overlapping periodogram FFT techniques to determine a nonparametric model of the cursor movement in response to the target sequence and characterizes the spectral properties of the tremor; (4) an ARMA time series KS which employs parametric modeling techniques to develop a model of cursor movement which is in turn used to find the undamped natural frequency and damping factor of the user; (5) a verbal reports KS and level which analyses the responses to questions asked of the the test subject and/or therapist concerning tracking ability; (6) a model building KS which examines units of information at the TI, spectral, ARMA, and reports levels and organizes the information; and (7) the gain KS which scans the user model and compares the information with a database of past performance and with the characteristics of other tremor users and posts suggestions for a new joystick gain if necessary.

EXPERIMENT SETUP

Referring to Figure 2, the prototype adaptive interface was developed and tested using an experimental setup whereby the OA software ran concurrently with a simple random 2-dimensional step tracking task. This task was run on a separate computer and was designed to maintain controlled clinical testing conditions. A therapist was involved in the testing and was asked questions by the OA relating to the participant's tracking ability. None of the software mentioned in this paper runs with commercial applications at this time.

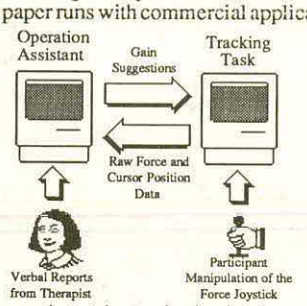

Figure 2: The experimental setup for the development and testing of the operation assistant.

EXPERIMENT RESULTS

A pilot study was conducted in order to: (1) determine the extent of asymmetrical transfer and range effects on performance when a gain change occurs; (2) and to develop the rules, frames, and numerical processing procedures to be used by the blackboard. The study was conducted using three persons with Friedreich's Ataxia (FA) and on three nondisabled persons.

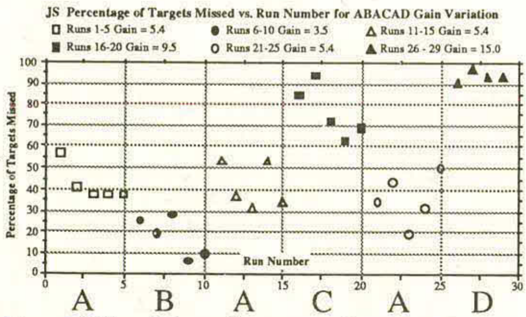

Figure 3: Gain variation and target errors for subject JS

A sample of the results for an ABACAD experimental setup for joystick gain changes for one of the FA subjects is depicted in Figure 3. This subject exhibited considerable resting and intentional hand tremor. Notice the performance approximately returns to the same level for the same control gain settings (Gain = 5.4).

Using the pilot study results, the OA was designed and implemented. A very simple experiment was then conducted on a single FA participant to see if convergence to a proper gain setting would occur.

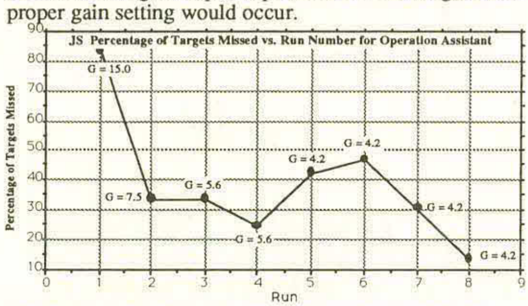

Figure 4: OA gain estimates and effects on performance for subject JS.

All knowledge sources were used to model the user but only the spectral KS was ready for use to infer the next gain setting after each run. The result using target errors as a simple performance measure is depicted in Figure 4.

These preliminary results are inconclusive but appear to indicate an improvement in performance. The OA suggested three gain changes over 8 sets of 32 targets. The performance variability was considerable at G = 4.2.

CONCLUSION

The initial result using the spectral KS of the OA was encouraging but the employment of the other knowledge sources remains to be done. Secondly, and more importantly, an experimental protocol is required which will allow for learning, transfer, and range effects to be separated out from from performance improvements resulting from use with the OA. Pilot study results using an ABACAD design showed promising results towards achieving this.

ACKNOWLEDGEMENTS

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Reverse Folding Wheeled Chair
A Third World Transportable Seating System For Disabled Children

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Abstract
Few disabled children in the third world have adequate seating systems. The objective of this project was to design a mobile, transportable, durable, low cost and lightweight seating system for children with disabilities. This device will be fabricated and used in the Third World, specifically Malaysia, thus made with locally available materials and appropriate technology. The chosen client is a 10 year old girl with cerebral palsy and resulting quadriplegia requiring special supports to maintain a sitting position. Various materials and designs were analyzed from which the following prototype was created.

Introduction
Between 1986-1987, I worked as a physical therapist with disabled children in Malaysia. Few supportive seating systems were available. Typically these children were left lying on their backs developing deformities such as scoliosis and dislocations. In addition, children had greater feeding, visual and learning problems and generally a very limited experience of life.

The seating system is designed for a 10 year old child in Malaysia who travels via car to school and requires a seating device both at home and school. She is also taken to stores, doctors and family outings; therefore, a collapsible, supportive device is essential. This child, weighing 80 pounds with cerebral palsy and resulting quadriplegia, pushes twice her body weight with her extensor tonus.

Design Requirements
Mobility: Operated by an assistant. Device able to traverse rough terrain - dirt, rocky, muddy and sandy roads.
Portability: Collapsible to fit in the trunk of a small car or on a bus roof. Lightweight - less than 30 pounds.
Durability: Withstand 3-5 years in heat, rain, insect infestation. Materials able to handle 100 foot pounds of force before bending.
Fabrication Constraints:
Materials available in Malaysia. Device can be made with hand tools (no welding) by non-technicians.
Child user Constraints: Supports required: Lateral and posterior head supports, lateral trunk supports, leg abductor, foot rests, trunk straps, seat belt and footstraps.
Cost: Device fabrication under US$40.00. Low maintenance cost.

Problem Analysis
Questionnaire A questionnaire was sent to 57 organizations in Third World countries and organizations working on designs for low cost, appropriate technology wheelchairs. Statistics (or estimates if none were available) were requested regarding types and frequencies of children's disabilities and degree of involvement (ie. ambulatory, requiring wheelchair, ability to wheel wheelchair). Respondents were also asked if there was a need for such a device. Questions were posed regarding the children's transportation needs. Lastly, I requested any designs or photographs of wheeled seating devices used in their area.
Rural Mexican Experience
Two weeks were spent at Projimo, Mexico, a rural rehabilitation clinic to gain hands on experience with children there, and in Culiacan, to assess current seating systems.
Materials Analysis
Materials considered and analyzed for the seating system frame included: steel tubing, PVC pipe, 3/8" spring wire rod, rattan and wood. They were evaluated for weight, availability, durability in rain and heat, ease of fabrication and cost. Bending tests were performed on PVC pipe, spring wire rod, and wood. Materials analyzed for the solid seating insert included wood, cardboard, cane and plastic webbing.
Collapsibility
Different methods of collapsibility were analyzed including wheelchairs, crossbraces, commercial strollers and folding chairs.
Axle/Wheel Systems
Sizes, types of rear and front wheel systems, as well as axle attachments were researched.
Literature Research
Commercially available supported wheeled seating devices, seating and positioning philosophies-requirements were studied.
Client
A 10 year old with cerebral palsy and resulting quadriplegia was chosen as a model. She was evaluated and measured as was her current seating system.

Results
Questionnaire/Projimo
32 responses were received, five included statistics or estimates of disabled children and their needs. Seven responses included designs or photographs of wheeled chair designs. Because the return rate of data was low, no statistical analysis was performed. However, the predominant opinion is that a tremendous need exists for wheeled chairs, both collapsible and noncollapsible. Some children have the opportunity to attend school, but this depends on their mobility. Many of them live in rural areas, miles from a road or school. If they do travel to school, they depend on someone to carry them. A percentage live in institutions. Approximately 20% of the children surveyed were unable to wheel their own wheelchair,

and required extra supports. None of the wheelchair designs received are collapsible.

In Mexico, most roads are unpaved and very rough, barely passable for automobiles, let alone bicycles and wheelchairs. Most disabled children do not leave their homes or villages. If they are taken anywhere, they are usually carried. An estimated 80% of the mothers with disabled children have back problems.

Results of Material Analysis

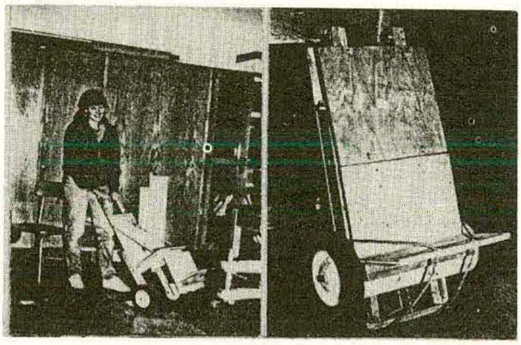
Wood was selected as the material for the seat insert and frame. Steel tube was rejected because welding is required. Although solid spring wire is an exciting alternative, it was also rejected as it requires soldering, special bending tools and availability is questionable. PVC tubing is another option, though its CREEP factor in hot climates limits its efficacy. Rattan is readily available in Malaysia, though it can not withstand rain and insect infestation.

Problem Solution

Because the child will not have the physical capability to wheel the device, the need for 24 inch tires is diminished. 8 inch tires are considered adequate. The problems of front swivel systems (ie. destruction of ball bearings, etc.) were eliminated by designing a chair which could be tipped on its back wheels when pushed. This also eliminated the need for a brake system, since the front stops can be used as brakes.

After analyzing various collapsing mechanisms a method of collapsing on the frontal plane was chosen. When the wheeled chair is put together the seat to back angle is 90 as is the thigh to leg angle and leg to foot angle. The axis of the wheels is 3/4" posterior to the vertical back. The chair folds into a neat flat package. Without added supports and cushion, it weighs 18 pounds. The seat back, base, leg and foot rests are made of 1/2" plywood. There are three pivoting points. The 2 x 2 legs attached to the wheels pivot 180 about a pin connection, utilizing a 3/8" dia. bolt connected to the 1 x 2 support screwed to the plywood seatback. When the legs are in the down position they are secured to a wood support by a bolt and easily removable wing nut. The 1 x 2 wood supports extend the posterior length of the seat back, base, and leg rest. The pin connection design requires that the distance between the 1 x 2 supports decrement twice the width of the support members at each connection. The ends of the support members act as pivot points and stops. After the legs are flipped up and back, the leg rest rotates up to the same plane as the seat base. Then, the seat base and foot rest pivot down and behind the seat back. When the chair is upright, stability is maintained by a rope knotted through two holes in the support members of the seat back. It then wraps down and underneath the front of the seat bottom. The rope can be easily adjusted for a tight fit.

The positioning supports must be custom made for the particular child's needs. This child will have semi-rigid trunk supports inside a canvass trunk strapping system, seatbelt and footstraps. Multiple glued layers of corrugated cardboard covered with 1" foam suffice for the cushion. The cardboard can be soaked, formed, and cut for custom fittings, such as a scooped out occipital support, antithrust seat and biangular back.



Reverse Folding Wheeled Chair

Discussion

The design has not as yet been evaluated by the client for problems. However, it has many unique features: it's lightweight, very compact, easy to fabricate and low cost. Because the folding mechanism allows the front of the seat back and base to be on the outside, a variety of seating supports can be placed on the chair. Additionally, the design can be easily modified for alternative wheels (ie. bicycle wheels with a quick release system).

Conclusions

The reverse folding wheeled chair addresses the problems of mobility and positioning for children in the Third World. Other materials, such as PVC, solid spring wire and steel tubing (used without welding) should be explored.

Acknowledgements

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TRUNK SUPPORT FOR A HORSEBACK RIDER WITH CEREBRAL PALSY

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ABSTRACT

A person with cerebral palsy wishes to independently ride horseback. The problem was to design and build a device that would provide the necessary trunk support to enable the person to ride safely, independently and comfortably.

Research in the handicapped horseback riding field was carried out to see if any existing designs would solve the problem. Information gathered from horseback riding sessions coupled with the extensive research helped to fuel brainstorming sessions. Design alternatives were discussed, concepts were tested, and a prototype was developed.

The final design features a device that mounts in front of the rider and lends support under the rider's arms. This design was chosen over other design alternatives because it met the design specifications and proved to be the most effective trunk support.

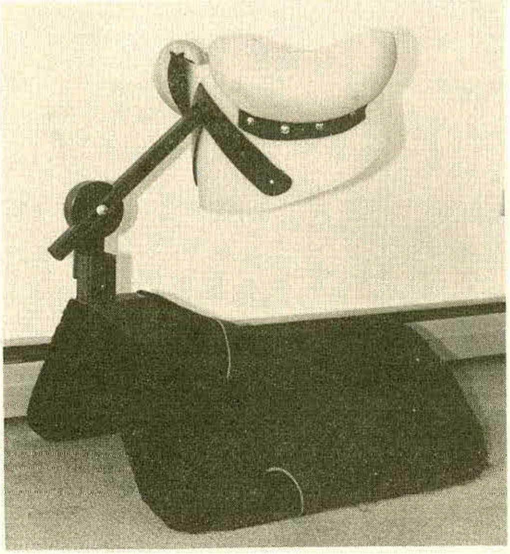

Figure 1.

DESIGN DEVELOPMENT

A person with cerebral palsy needs a supportive system to enable him to independently ride horseback. For safety reasons, the person must not be tied in any way to the horse or saddle.

Through research of existing methods currently employed by handicapped riders, the apparatuses used for riding and through research of the special needs of our client, many ideas were generated for the trunk support. Riding sessions helped define the design parameters for the needed support. Brainstorming sessions with experienced equestrian riders provided additional ideas for the trunk support. Testing of a prototype design indicated more important parameters which were included in the final design.

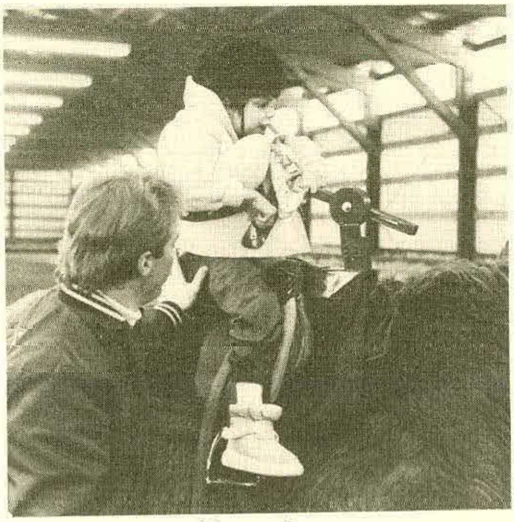

Figure 2.

DISCUSSION OF FINAL DESIGN

The final design is a trunk support system (FIGURE 1). The reason for a chest support rather than a back support is to allow the rider to escape in a rearward direction in the event of a run-away horse. The support wraps partially around the sides of the rider, extending up and under the rider's arms and thereby providing the required trunk support (FIGURE 2).

The trunk support system is composed of two major components. The first component is a polyethylene plastic saddle blanket mounted to a steel sub-frame. The covered plastic saddle blanket is placed between the normal saddle blanket and the saddle. For stability, the plastic saddle blanket is held onto the horse by the weight of the saddle/rider and its own cinching system. The second component consists of an adjustable linkage and the chest support. The adjustable linkage allows adjustment to fit any rider. The chest support, which is made of polypropylene plastic, is attached to the adjustable linkage. For comfort it has covered foam padding under the arm area. Once the device has been adjusted to the individual, the chest support can be easily detached from the plastic saddle blanket, allowing for easy mounting and dismounting.

This trunk support system is lightweight, approximately 25 pounds, and does not hinder the rider's control over the horse.

This design meets the requirement of the NORTH AMERICAN RIDING FOR THE HANDICAPPED ASSOCIATION that the rider not be tied to the horse or saddle in any way. Preliminary testing of the final design showed that the design provides adequate trunk and balance support for the rider while still allowing for an emergency dismount. The device also places the individual in the correct riding position. A ROHO saddle cushion is utilized to further insure comfort and minimize the possibility of pressure sores.

CONSTRUCTION OF DESIGN

Using a horse, positive and negative plaster molds were constructed from the horse's back. Utilizing the molds, the plastic saddle blanket was formed using polyethylene plastic softened in a radiant heat oven. The chest support was also formed using the radiant heat oven to soften the polypropylene plastic and then forming it around a tubular mold. The steel sub-frame was hand-formed and welded to fit the shape of the horse's back. The plastic saddle blanket was padded, painted, and covered with a water resistant carpet. A sur-single cinch system was then attached.

An adjustable, detachable linkage was machined and welded using various machining equipment such as an engine lathe, vertical mill, drill press, grinder, and TIG welder. Special knurling methods were used on the friction surfaces of the adjustable ring to prevent slippage. A hand formed steel frame was built to attach the chest support plastic to the adjustable linkage. Covered arm pads were sewn and attached to the plastic chest support.

MARKETING ASPECTS

The materials for the support which include the plastic, molds, steel, attachments, and miscellaneous items cost $200. The $300 ROHO saddle cushion was donated. Design, development, and construction time was not considered in the budget.

Depending on the levels of production, the cost of the trunk support system may be reduced to the point where it could be economically viable for many individuals and organizations.

Considering the number of horseback riders with disabilities and the lack of any support devices of this kind, the design should have excellent market potential.

ACKNOWLEDGMENTS

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THE PIVOT ASSIST SEATING SYSTEM - PASS

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ABSTRACT

The PASS Relaxation Chair has been designed for individuals with disabilities that make it difficult to rise from standard easy chairs. It offers a therapeutic level of assist, is comfortable for long sitting durations, fits into a residential setting, and does not draw attention to the disability of the user. It accomplishes this partially through the unique pivoting action of the seat pan. This paper describes the Pivot Assist Seating System and the research that led to the design of the PASS Relaxation Chair.

INTRODUCTION

There is a large group of people, the majority of whom are elderly, who have difficulty getting into and out of chairs due to a physical disability. This limitation in mobility greatly reduces the capacity to function independently, which is essential to both physical and emotional health. Products must be available that help in the management of this condition. The most obvious and effective product is the specialized chair. The market is currently full of seating products that are only partial solutions to this problem. Some of these products overcompensate for the physical handicap of the user, depriving them of what could be a healthy therapeutic activity. Many of these products have an institutional appearance or draw attention to the disability of the user which can cause the individual to feel self-conscious. Prejudice toward disabled individuals does exist, and it is understandable that mentally healthy and active older people do not want their physical limitations to misrepresent their mental capabilities.

The PA Seating System has been designed to meet the needs of this group of individuals more completely than existing products. It can be described as a 'low-technology' solution, because it solves the problem with a simple solution - the form of the chair itself. There is no external power source. Sometimes, as in this case, a low-tech solution can only be obtained by synthesizing information and techniques found in what are traditionally considered to be separate disciplines.

LITERATURE REVIEW & MARKET STUDY

Literature was accessed from a wide range of fields. A profile of the physiology, psychology, anthropometrics, demographics, and life styles of the U.S. elderly population was compiled. Archival research was also conducted into: seating design and research techniques; seating design for the elderly; and the biomechanics of the sit-to-stand motion. A market study was conducted which consisted of a search for current products, prices, and promotion and distribution strategies. Information was obtained that led to an estimation of the current and potential size of the market. This study suggests that there is a large, expanding, and under-served market segment with a need for this type of product - namely the *independent* elderly consumer. Much of this information was compiled in an 80 page document. A copy of the report or bibliography can be obtained from the author.

The information from the literature review and market study was used to develop the following performance criteria. The product should: 1) promote a safe and easy egress by offering a therapeutic assist; 2) address the ergonomics of the major user group (the elderly); 3) assist the user without drawing attention to the disability; and 4) be a profitably marketable product.

An analysis of the current product offerings revealed that none of the products fulfill all of the performance criteria. One of the most popular products is the electric lift chair, which has a seat that is raised and lowered by a motor. An important criticism of the electric lift chair is that, "they place patients in a passive role with regard to egress, thus eliminating the beneficial exercise associated with normal chair egress." [1] Also, a lift chair draws a great deal of attention to the user's disability when in motion. Hip chairs, geriatric chairs, spring-loaded chairs and seat cushions all have similar problems. While there are a few examples of ergonomically designed chairs that offer a therapeutic assist through the form of the chair itself, such as the Warren Chair, the amount of assistance is limited due to the relatively low seat height.[2] Although a chair such as this is a useful product for the mildly to moderately disabled population it may not offer enough of an assist for the more severely disabled individual.

After this analysis of available products, computer manikens of the elderly population were developed and used to test possible chair concepts. Several adjustable experimental seating bucks were built to determine the effectiveness of the concepts. A seating buck is an apparatus that simulates the proportions and motions of a seat.

THE PASS RELAXATION CHAIR

The Relaxation Chair is only one example of how the PASS concept can be applied. The Relaxation Chair has been designed for moderately to severely disabled individuals attempting to live independently in the community. The chair has been designed to look like a normal, attractive piece of furniture for the home and to be comfortable over long sitting durations. It is intended to be used for reading, relaxing, watching TV, conversing, etc. The price would be comparable to other high-quality easy chairs. It would be distributed through a national furniture retailer and home health care supply retailers. The chair should be promoted as furniture for the 'mature consumer', and references to disabilities should be minimized.

The core concept of the PA Seating System stems from bio-mechanical experiments which have shown that a relatively high seat pan can bypass the most stressful part of the sit-to-stand motion.[3] The designers of hip chairs have taken this approach. Although the high seat is a simple and effective solution in reducing hip and knee stress, two of the problems with high seats and hip chairs is that they are difficult to get into and usually uncomfortable. The PA Seating System avoids these drawbacks of a high seat by placing the seat on a pivot. When the user begins sitting, the seat tilts forward slightly to aid entry. As the user's center of gravity shifts the seat tilts backward, placing the user in a comfortable long-term sitting posture. The motion of the seat is not highly noticeable. This design necessitates a foot rest, since the feet might not touch the ground when the user is fully seated. The chair is designed in two sizes; the selection of the correct model depends on a combination of the physical size of the user and the severity of the disability. For example, a small person with a high degree of disability may require the larger model because the higher seat would make standing easier. With this two model system a therapetic level of assistance could be attained for a broad range of users.

The arms of the chair protrude forward, past the front edge of the seat, and are situated at a height which offers maximum leverage when standing.[4] The sides of the chair hide the pivoting motion of the seat, the fact that the seat is higher than normal, and the footrest (when retracted.) The chair was designed to make the necessary but unusual proportions seem natural. The form and appearance reflect the fact that a great majority of the people using this chair will be women. The chair is constructed with traditional furniture manufacturing methods - upholstered foam padding on a wood frame. The armrest and footrest are made from laminated wood. Low density rubber stops keep the seat from moving abruptly when pivoting, and return it to its rest position when not in use. The footrest is positioned by a hand control located on the inside of the armrest, and rides on standard bearing slides. The footrest is adjustable in two degrees of motion, and can be moved inward or outward to adjust to a range of leg lengths.

Grandjean's rest chair seat profile for notalgic individuals was used as the basis for the PASS Relaxation Chair's seat profile.[5] Aside from the obvious increase in seat height, the profile was adapted to better fit the elderly population. The lumber support, backrest inclination, backrest height, and seat pan depth were altered. Pillows were added that can be arranged to accomodate the large variety of back shapes and head heights.

PRIMARY RESEARCH

After the initial design of the 'core concept' was complete, a substantial amount of information was needed for refinement that could not be found in the literature. Three studies were set up to help supply this information. They were designed to gather only the basic and necessary data with which to continue development, and to function as learning experiences for more accurate and comprehensive studies in the future.

Anthropometric Study

This study was conducted at a nursing home with the experimental buck. The goal of the study was to obtain data pertaining to the dimensions of the chair, and to informally determine how elderly people with arthritis and related conditions respond to the design. The subjects were recorded on 35mm slide and VHS videotape. The final dimensions for the Relaxation Chair were generated from an analysis of the slides and videotape. In general, the subjects felt that the chair was safe and easier to get out of, while being more comfortable than the geriatric chairs in the building. Also, the aides and resident physical therapist noticed a marked improvement in the subject's ability to rise from the buck.

Biomechanical Study

This study was initiated to objectively determine if a PASS chair is easier to get out of than other chairs designed for this purpose, and if so, to what extent. Six CD cameras were set up to record the motion of the subject standing from the experimental buck. These images are fed into a computer along with pressure plate data from the base of the chair and a platform under the subject's feet. This data could be used to determine the moment around the knee joint which is a good indicator of knee stress. This study has not been completed.

Visual Comfort Study

This study was conducted to investigate design elements in chairs that project an image of comfort to an elderly population, under the assumption that a chair will more likely be used for the first time, and purchased, if it looks comfortable. Questionnaires were distributed at a senior citizen center. The results showed that the most significant visual cues to comfort were: a heavy, plush padded look; a footrest or ottoman; and, less significantly, recline and a high back rest.

CONCLUSIONS

The PA Seating System seems to be effective in offering a safe, therapeutic assist to users when rising without drawing attention to their disability. Observation of disabled individuals using the experimental buck, supports this statement. Although the Relaxation Chair is in the early stages of development and requires more testing and refinement, the product meets many of the performance criteria and appears to have much potential. Additional applications of the PA Seating System are also being explored, such as a PASS rocking chair.

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TWO SWITCHLESS SELECTION TECHNIQUES USING A HEADPOINTING DEVICE FOR GRAPHICAL USER INTERFACES

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ABSTRACT

The Graphical User Interfaces of current computers can be a barrier to people with physical disabilities who do not have the fine hand control necessary for the manipulation of common pointing devices. This paper describes two switchless selection techniques which give a person the freedom to use simple head gestures to emulate the standard mouse button selection methods.

INTRODUCTION

A wide range of devices and programs have been developed and modified to allow people with disabilities to have access to computers. Until recently, however, the efforts have concentrated on text-based applications and keyboard emulators. Graphical User Interfaces such as Microsoft Windows™ and IBM OS/2 Presentation Manager™ are quickly replacing the conversational style of human-computer interaction. Although this style of interface can make computers easier to use, the fine hand control needed to manipulate a typical pointing device, such as a mouse or a trackball, is a barrier to many people with physical disabilities.

BACKGROUND

A pointing device which is used to emulate a mouse must implement specific *selection methods* which are normally accessed by pushing and releasing mouse buttons. The common selection methods include single clicks, double clicks, dragging. These methods are translated by various application programs into various *selection tasks* such as selecting a character or a word, highlighting a phrase, starting an application program, or moving a file. Tasks such as these are typically performed in word processing applications such as Microsoft Word™ and in operating system interfaces such as Microsoft Windows™, Presentation Manager™ and the Macintosh Multifinder™.

People with good head control can use a headpointing device to emulate the mouse and move a cursor about the screen; however, it is still quite difficult to make selections using the mouse buttons. An adapted device typically provides external switches such as sip-and-puff or eyebrow switches to make the selections; however, this is not an ideal solution. As the user tries to click a button while pointing at a particular location on the screen, the extra effort causes the head to move, resulting in an erroneous selection. The problem is aggravated when the switch must be held down while moving the screen cursor in order to implement dragging.[1]

What is needed is a way to emulate the methods of selection, *without external, adapted switches*. This is possible by using a natural head gesture: the nod. Gestural hand input is not a new idea in the field of human computer interaction [2]; however, using *head gestures* to implement switchless selection methods is a novel approach. Using a combination of pauses, and head nods and shakes, it is possible to differentiate among several different intended selections. The measurable parameters include pause time along with the direction, duration, speed and distance of movement. These have been used to formulate several selection techniques, two of which are described in the following section.

TWO SELECTION TECHNIQUES

Multi-Level Pause Time

Using a simple pause or dwell time is a common technique for implementing a single mouse button click in the selection of characters from a visual keyboard. The person holds the pointer steady over the intended target for a predetermined amount of time before the selection is made by the system. By expanding this technique to multiple levels of pause time, it is possible to differentiate between more selection methods. The state transition diagram in Figure 1 illustrates this.

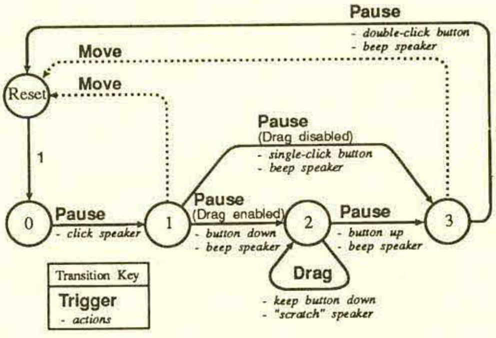

Figure 1. State transition diagram for the "Multi-Level Pause" technique.

In state 0, the system waits for the user to pause within a given area. When a pause has been completed, a warning click is heard and the system transfers to state 1. Continuing to hold completes a longer pause and causes the system to beep and emulate the pushing down of the mouse button, transferring to state 2. In this state, an object on the computer screen may have been selected which the user can drag to a new location on the screen, and a scratching sound is heard. Pausing longer sounds another beep as the emulated mouse button is released and the system transfers to state 3. A further pause here causes one final beep and emulates a double click of the mouse button before resetting and returning to state 0.

Using a separate configuration program, the drag method can be disabled, allowing a transition from state 1 to state 3 directly. This is similar to the old technique of emulating a single mouse button click using a simple pause for selection.

The Nod and Shake

The technique of using multi-level pause times works well, but it is limited to only one mouse button and it can be confusing to realize which state the system is in. It also becomes increasingly difficult to hold the cursor steady for extended periods. These difficulties can be overcome by using natural head gestures to speed up the selections.

Figure 2 illustrates the Nod and Shake technique of emulating the mouse button methods. As with the multi-level pause time, an initial pause causes the transition from state 0 to state 1. In addition, a "cursor clutch" is set, which locks the cursor in position on the screen. From state 1, each selection takes two stages: an initial movement or gesture is followed by a reversal of the movement direction. For instance, a gesture in the downwards direction (nod down) causes a transition from state 1 to state 2 accompanied by a speaker click. Reversing directions to return to the original position completes the nod and emulates *a single click* of the left mouse button, releasing the cursor clutch and sounding a final beep. The system is then reset and returns to state 0. Similarly, an upward gesture immediately followed by a downward return emulates a *double click* of the left mouse button and a gesture to the right and back emulates a single click of the *right button*. If the appropriate gesture is not completed within a specified time the system is reset and no mouse button is emulated.

Dragging is not done directly with the Nod and Shake technique. Instead, the user pauses long enough for the Multi-Level Pause technique to begin.

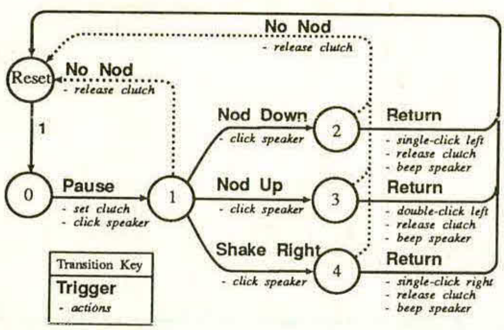

Figure 2. State transition diagram for the "Nod and Shake" technique.

IMPLEMENTATION

The Long Range Optical Pointer, available from Words+, Inc., and originally developed at the TRACE Research and Development Center was modified to provide a signal with acceptable resolution and stability.

The two techniques above were implemented in a mouse device driver under Microsoft Windows 2.0 to provide access to a large number of existing and future applications. The state machines for the two techniques run concurrently, allowing either technique to be used at will.

A standard Windows application was written to allow the user to customize the device driver and test changes interactively. Each of the two selection techniques can be disabled or enabled independently. Furthermore, the dragging action can be disabled for the multi-level pause time and the cursor clutch can be disabled for the nod and shake technique. The program also allows adjustment of the pause interval, the pause target size, the threshold for the nod and shake distance, and the maximum time for the completion of a gesture.

RESULTS

The modified headpointer has been tested with seven clients to date. Three of the clients had spinal cord injuries resulting in quadraplegia, three had athetoid Cerebral Palsy, and one had a peripheral nerve syndrome.

In comparative pointing trials with other devices (joystick, trackball, and digitizing tablet), one of the clients with a spinal cord injury along with the client who had the peripheral nerve syndrome found the headpointing device to be the most effective. The other client with the spinal cord injury found performance to be equal with that of a joystick.

Comparative trials have not been performed yet using the selection techniques. Instead, the techniques have been used in a painting program to test their usefulness in performing realistic computer tasks. The clients who had good headpointing skills found the techniques to be effective and useful.

DISCUSSION

Clients have successfully used the selection techniques with a painting program on the computer. This has been a good indication of the efficacy of the selection methods.

Some training is necessary in order to use the nod and shake technique consistently. It will be necessary to provide a small training utility for this, perhaps within the already existing configuration utility.

Good feedback is required by the user to know what state the system is in. The speaker clicks are sometimes too quiet to be heard in a noisy environment and the beeps become confusing because they all sound the same. Further work will be done to create a more interesting range of audio cues.

The configuration utility allows a great variety of parameters to be set. The affects of adjusting these parameters and their interrelationships are not fully known. Tactics and criteria for finding optimal values will be explored.

CONCLUSIONS

The two simple techniques of using pauses and head gestures to emulate mouse button selection methods have been used successfully. Further work is required to provide a training utility and improve the user feedback. More research is needed to find optimal settings of the selection parameters.

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