User perceptions of neural stimulation-facilitated transfers across surfaces of different heights

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INTRODUCTION

Individuals with lower extremity paralysis rely on their upper extremities to accomplish activities of daily living, like performing transfers from their wheelchairs to a bed, tub/shower bench, toilet, couch, etc. The sitting pivot transfer is the conventional transfer method for individuals with low-cervical to low-thoracic spinal injuries [1]. To initiate this type of transfer, individuals position their wheelchair as close as possible to the target surface. Moving towards the edge of the wheelchair seat, they place one hand on the wheelchair and one on the target surface. Leaning forward and sideways, they use their upper extremities to lift, rotate, and lower themselves onto the target surface. It is estimated that these transfers are performed 15-20 times a day [2] on average. Even with assistance from a family member or caregiver, the repeated performance of these weight-bearing tasks places high mechanical loads on the shoulders, thus significantly increasing the risk for shoulder overuse and injury [3]. It is critical to preserve the joint and functional integrity of the shoulders during transfers [4] since they can exacerbate the shoulder pain and instability that are prevalent in individuals with spinal cord injuries.

Neural stimulation may efficiently assist conventional transfer techniques. This involves applying low-energy electrical pulses to the nerves that control the muscles to stimulate functional movements. Research groups have activated the bilateral quadriceps to augment conventional transfers in individuals with paraplegia, which provided an assistive force to help lift participants transferring between surfaces of even heights with their self-preferred movement strategies [5]. Previous findings suggest that stimulation-assisted transfers may reduce load on the upper extremities of the user [5]. Although these results are encouraging, their generalizability is limited because only transfers between surfaces of the same height were investigated. Neural stimulation assistance may be more beneficial for transfers between uneven heights, particularly low to high surfaces. Furthermore, stimulation was limited only to the quadriceps, and incorporating the muscles of the hips and trunk may greatly improve transfer efficiency. As an alternative, other studies demonstrated that implanted neural prostheses employing functional neuromuscular stimulation (FNS) to the trunk, hip, and knee extensors enabled persons with low-cervical to low-thoracic spinal injuries to stand and transfer with minimal assistance from a caregiver [6]. Standing pivot transfers entail elevating the body with the upper extremities via a walker, rotating, and lowering the body onto a new surface. To assess performance, participants executed two transfer methods (standing transfers with FNS and conventional transfers without FNS) between surfaces at the same height (level transfers) and at the maximum height above which the transfer could not be performed without FNS (failure height). Subjective perceptions of effort and assistance during transfers were assessed with a seven-point usability scale (Usability Rating Scale or URS, Figure 1) with ratings from very difficult to very easy [7]. Ratings for level transfers performed with both preferred conventional transfers. This difference in preference may be attributed to participants having to stand upright before transferring, which took additional time with stimulation due to the need to activate and deactivate the system. Compared to conventional transfers, standing transfers were rated easier with stimulation when participants performed transfers at failure height. However, this work focused only on standing pivot transfer maneuvers and did not address the more commonly performed sitting pivot transfers. Addressing this gap in the knowledge, this pilot study is designed to determine the effects of using FNS to augment conventional sitting transfers between surfaces of uneven heights. We hypothesize that participants will prefer FNS-assisted sitting transfers to various heights over conventional transfer methods. We expect that FNS will decrease subjective perceptions of effort and stress at the shoulders and increase subjective ratings of safety and comfort. We also hypothesize that FNS will improve the efficiency of sitting pivot transfers between uneven surfaces, with respect to maximum difference in height, time required to perform transfers, and number of attempts required to successfully perform the transfer.

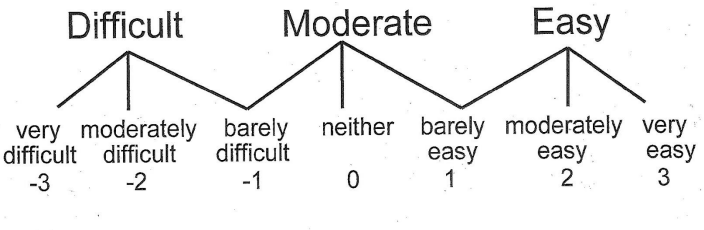

Figure 1. Usability Rating Scale (or URS) to measure perceived effort

METHODS

Two neural implant recipients (P1 and P2) participated in pilot experiments to determine failure height. P1 is a 62-year-old male with motor complete paraplegia (T4, AIS B) and P2 is a 48-year-old male with motor incomplete tetraplegia (C5, AIS C). To facilitate transfers with FNS, the bilateral quadriceps and posterior portion of the adductor magnus were targeted for activation in P1, while the bilateral quadriceps were targeted for activation in P2. Experiments were performed at the Motion Studies Laboratory of the Louis Stokes Cleveland Department of Veterans Affairs Medical Center and both subjects provided informed consent prior to participating in the study. Participants performed transfers from their own wheelchair to a height adjustable mat table (Figure 2, top). A successful transfer was defined as an unassisted transfer from their wheelchair to the mat. Experiments were initiated at a height level to the wheelchair and the mat height was increased until either participants were no longer able to transfer to the higher surface, or the maximum height of the mat was reached. Two transfers were performed at each height (level and failure height), one with FNS and one without FNS. Participants were allowed a maximum of two attempts to perform each transfer, and after each successful attempt participants provided a rating for perceived effort (URS), perceived stresses at the shoulder (Modified Borg CR-10, as defined in [8]), comfort and safety (Likert-type scales as described in [9]). These scores and their meaning for these surveys are listed in Tables 1 – 3, respectively. After performing level transfers and transfers at their failure height, participants identified their preferred transfer method (FNS or no FNS). For each transfer, the number of attempts, time required to complete the transfer and transfer height were recorded. To capture transfer performance from a lower surface to the wheelchair, participants transferred from mats stacked on the floor to the wheelchair (Figure 2, bottom). A mat was removed from the stack until failure height was attained. For level and non-level transfers, the number of attempts, time to complete transfer, and subjective ratings with and without FNS, and overall preference were compared. In addition, for non-level transfers, maximum height (relative to the wheelchair) was computed. Participants were treated as their own controls.

Figure 2. Participant performing a level transfer (wheelchair to mat table, top) and performing a nonlevel transfer (mats on floor to wheelchair, bottom).

Table 1. Perceived shoulder stress (Modified Borg CR-10 Scale)

Score	Meaning
10	Very, very strong
8-9	
7	Very strong
6	
5	Strong
4	Somewhat strong
3	Moderate
2	Weak
1	Very weak
0.5	Very, very weak
0	Nothing at all

Table 2. Perceived comfort (5-point Likert-type Scale)

Score	Meaning
1	Uncomfortable
2	Somewhat uncomfortable
3	Neither uncomfortable or comfortable
4	Somewhat comfortable
5	Comfortable

Table 3. Perceived safety (5-point Likert-type Scale)

Score	Meaning
1	Unsafe
2	Somewhat unsafe
3	Neither unsafe or safe
4	Somewhat safe
5	Safe

RESULTS

The height of P1's wheelchair was 52.1 cm and the height of P2's wheelchair was 63.5 cm. P1 provided the same ratings for the level transfer from the wheelchair to the mat with and without FNS: perceived effort was very easy (URS = 3), perceived stresses at the shoulders were moderate (Borg = 3), and was comfortable and safe performing the transfers (Comfort and Safety = 5). Time to transfer was 3.5 s without FNS and 4.9 s with FNS. Stimulation supplied to the right quadriceps was 25 μs with a current of 18 mA, 40 μs to the left quadriceps (current = 2.1 mA), and 10 μs to the bilateral posterior portion of the adductor magnus (current = 20 mA). P1 preferred performing level transfers without FNS. P2 rated the level

transfer without FNS as follows: perceived effort was barely difficult (URS = -1), perceived stresses at the shoulders were strong (Borg = 6), and felt neither comfortable nor uncomfortable as well as neither safe or unsafe performing the transfer (Comfort and Safety = 3). The level transfer with FNS was rated as follows: perceived effort was barely difficult (URS = -1), perceived stresses at the shoulder was strong (Borg = 5), perceived comfort was somewhat uncomfortable (Comfort = 2) and perceived safety was neither safe nor unsafe (Safety = 3). Time to transfer was 8.3 s without FNS and 6.7 s with FNS. Stimulation to the bilateral quadriceps was supplied at 130 μs (current = 1.8 mA). P2 preferred performing transfers with FNS.

P1 reached failure height when the difference in relative height was 21.6 cm (Table 4). While transferring to failure height without FNS, P1 reported that perceived effort was very difficult (URS = -3), perceived stresses at the shoulders were strong (Borg = 6), and that he felt somewhat unsafe and somewhat uncomfortable performing the transfer (Safety and Comfort = 2). While transferring with FNS, perceived effort was reported as moderately difficult (URS = -2), and perceived stresses at the shoulders were strong (Borg = 6). P1 reported feeling uncomfortable (Comfort = 1) and somewhat unsafe (Safety = 2) while performing the transfer. Time to transfer with FNS was 18.1 seconds and 25.1 s without FNS. Once the relative transfer height increased to 10.2 cm or greater, the stimulation pulse width to the right quadriceps was increased to 45 μs and 60 μs to the left quadriceps. Transfers with FNS were the preferred transfer method for non-level transfers from the wheelchair to the mat. While performing non-level transfers from the floor to the wheelchair, P1 reached failure height at 27.9 cm. Transfers without FNS were attempted twice at this height, without success. However, the transfer with FNS was successful and was rated as follows: moderately difficult perceived effort (URS = -2), moderate perceived stresses at the shoulders (Borg = 3), perceived comfort and safety were somewhat comfortable and somewhat safe, respectively (Comfort and Safety = 4). Time to transfer was 12.4 s. For these transfers, stimulation supplied to the right quadriceps was increased to 65 μs and 80 μs to the left quadriceps. FNS was the preferred method for performing non-level transfers from the mat to the wheelchair.

Table 4. Perceptions of transfer performance at failure height (wheelchair to mat)

Participant	Stimulation Condition	Relative Height (cm)	URS	Borg	Safety	Comfort	Time (s)
P1	None	21.6	-3	6	2	2	25.1
	FNS		-2	6	2	1	18.1
P2	None	10.2	1	5	3	3	9.8
	FNS		0	5	3	3	8.7

P2 was able to successfully transfer from the wheelchair to the mat table with and without FNS, at the maximum height of the table (11.4 cm relative to wheelchair, Table 4). The transfer without FNS was reported as follows: neither easy nor difficult perceived effort (URS = 0), strong perceived stresses at the shoulders (Borg = 5), and felt neither comfortable/safe nor uncomfortable/unsafe (Comfort and Safety = 3). The transfer with FNS was rated as follows: barely easy perceived effort (URS = 1), strong perceived stresses at the shoulder (Borg = 5), and felt neither comfortable/safe nor uncomfortable/unsafe (Comfort and Safety = 3). Time to transfer without FNS was 9.8 s, while time to transfer was 8.7 s without FNS. P2 preferred performing these non-level transfers with FNS; and was unable to perform transfers from the floor to the wheelchair with or without FNS.

DISCUSSION

This pilot study explored the perceptions of neural prosthesis recipients performing transfers across level and non-level surfaces with stimulation. User preference for transfer method across surfaces of level heights differed, which may be attributed to each participant's level of impairment. However, for transfers across surfaces of uneven heights, both participants preferred performing transfers with FNS. In general, perceived effort was reduced when transferring from the wheelchair to the mat table with FNS. Although the scores for perceived shoulder stress were the same while transferring from the wheelchair to the mat table (without and without FNS), they are consistent with those reported in other studies assessing the biomechanics of independent transfers without FNS [10]. The implementation of FNS also reduced the transfer completion time. Given these encouraging preliminary findings, failure height tests will be conducted with additional participants, and future work will also focus on collecting repeated measures of non-level transfers with and without FNS. During experiments for the latter, transfers will be performed in the community (transferring from a low soft couch to the

wheelchair, transferring from car simulator to wheelchair, etc.) to understand user perceptions of stimulation-assisted transfers and assess transfer performance in more realistic scenarios.

CONCLUSIONS

Neural stimulation was implemented to assist independent level and non-level transfers in two neural prosthesis recipients with lower extremity paralysis. User perceptions of transfer performance with stimulation were assessed with respect to effort, stresses at the shoulder, comfort, and safety and compared to transfer performance without stimulation. Transfer performance was also assessed quantitatively with respect to time to transfer, failure height, and number of attempts. Preliminary results suggest that transfers with FNS were preferred when performing non-level transfers. In general, non-level transfers performed with FNS were perceived to require less effort and had a shorter completion time than those performed without FNS. Stimulation-assisted transfers may enable individuals with paralysis to transfer across surfaces of different heights independently and efficiently, by reducing perceived effort and reducing the time required to complete the transfer.

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