USER EVALUATION OF AN ALTERNATIVE MANUAL DRIVE SYSTEM FOR WHEELCHAIR MOBILITY

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ABSTRACT

Commonly-used hand rim propulsion methods are inefficient, causing an increased risk for musculoskeletal impairments. Lever-drive options increase efficiency of wheeled mobility devices and reduce physical strain on users, but design improvements are necessary before lever-driven wheeled mobility devices are practical for everyday use. The objectives of this study were to 1) assess the durability, appearance, stability, safety, comfort, ease of use, and performance of the RoScooter and RoTrike and to 2) determine what improvements could be made to the devices based on user suggestions. The study enrolled 13 persons with physical disabilities who performed various mobility tasks and rated the performance of the two devices. Users were also graded on task performance by study personnel. Users enjoyed the devices, but improvements in adjustability, reversal methods, and operation options to appeal to a wider range of consumers are needed before the ROTA devices are able to replace or supplement current wheeled mobility devices.

INTRODUCTION

Wheeled mobility devices (WMD) are essential for independent living for those with limited mobility. However, nearly 70% of WMD users experience upper extremity pain or injury as a result of day-to-day device operations (Mandy Rehead, McCudden, Michaelis. 2014). One of the most common methods of wheelchair propulsion is via hand rims. However, hand rim propulsion is considered to be an inefficient form of locomotion (van der Woude, Veeger, de Boer, Rozendal 1993). The use of hand rims leads to relatively high cardiorespiratory responses and high levels of strain on the musculoskeletal system (van der Woude, Veeger, de Boer, Rozendal 1993). The extended use of hand rim propulsion may result in long term upper extremity pain and a higher risk for upper limb injuries (van der Woude, Botden, Vriend, Veeger 1997).

Lever-driven WMDs are mechanically more efficient than hand rim propelled WMDs [2]. A lever-drive system involves a pushing or pulling action on the end of a tiller (Mandy Rehead, McCudden, Michaelis 2014). Lever-driven devices have been shown to require less vertical reaction forces to propel than hand rim operated devices, increasing mechanical efficiency (Mandy Rehead, McCudden, Michaelis. 2014). These systems have also been shown to decrease physical strain due to continuous motion, the use of flexor and extensor muscles, and less complex coupling of the hands during operation (van der Woude, Botden, Vriend, Veeger 1997).

While lever-driven devices have many benefits, design flaws have limited their use on a larger scale. Lever-drive devices are often associated with being heavy, difficult to maneuver in tight spaces, and difficult to move over rough surfaces. Lever-driven systems are limited by the levers' fixed action range and lack of a free wheel, which allows for maneuverability in tight quarters (Engel, Seeliger, 1986). Other disadvantages associated with lever-drive devices include speed limitations due to stroke rate, inability to rest in between strokes, lack of a castering action, and difficulty with mounting ramps (McLaurin, Brubaker, 1985). Because of these features, lever drive devices are not always ideal for everyday use despite their mechanical advantages over hand rim-propelled WMDs.

Currently, lever-drive devices are most commonly used in Europe (McLaurin, Brubaker, 1985). The majority of lever-drive devices are for outdoor recreational use, with very few options for indoor use (Engel, Seeliger, 1986). Lever-drive WMDs have recently become more popular in North America for sports-oriented and recreational purposes (van der Woude, Botden, Vriend, Veeger 1997). However, an emphasis has been placed on developing lever-drive WMDs for daily use. The purpose of this study was to 1) assess the durability, appearance, stability, safety, comfort, ease of use, and performance of two new lever-driven WMDs, the RoScooter and RoTrike, and 2) determine what improvements could be made to the RoScooter and RoTrike based on user suggestions. Findings from the study will indicate possible areas of improvement, making lever-driven WMDs more feasible for daily use.

METHODS

Subjects: The study received approval from the University of Pittsburgh's Institutional Review Board. Thirteen individuals with physical disabilities participated in the study. Inclusion criteria for users were 1) being between the ages of 18 and 80 2) having a mobility impairment that requires the use of a WMD or makes it difficult to ambulate for more than 25 feet 3) weighing less than 250 lbs 4) having adequate body function to operate a drive mechanism that stimulates a rowing motion 5) not requiring complex seating adjustments and 6) being able to sit upright for at least 4 hours. Users were excluded from the study if they had any active pressure sores or a history of pressures sores that could be exacerbated by participation in the study. Users were tested at the Hiram G Andrews Center in Johnstown Pennsylvania during November 2014 and at the Human Engineering Research Laboratories in Pittsburgh, Pennsylvania between November 2014 and December 2014.

Experimental Protocol: Users completed questionnaires that included information, such as age, gender, and race and wheelchair and/or scooter experience. Subjects were then instructed on the operations of both the RoScooter and RoTrike via a power point presentation and demonstrations by the study personnel. The RoScooter and RoTrike can be seen in Figure 1. Subjects were given the opportunity to practice using the devices in an open space and to ask questions about device operation. The subjects were then taken through a course simulating common mobility tasks (Tables 1 and 2). Users were graded on their performance with the devices. Scoring was based on the Wheelchair Skills Test scoring system, where a score of 2 indicated that the subject could perform the task safely, a score of 1 indicated that the subject could perform the task, but required assistance, and a score of 0 indicated that the task could not be attained. (Dalhousie University, 2012).

Figure 1. RoScooter (left) and RoTrike (right) (ROTA, 2014)

If the subject could not perform the task successfully on their first try, they repeated the task up to three times for each device. After completing the driving course, subjects were given a survey for each device asking questions regarding ease of use, safety, appearance, relevance to needs, and likelihood of purchasing. Subjects rated tasks by marking on a visual analog scale (VAS) how difficult they felt each task was, where one end of the continuum was "0", representing very difficult, the midpoint was "5" representing neither easy nor difficult, and the end was "10", indicating that the task was very easy. The line was 10 cm long and was converted to a numerical value by measuring how far away the mark was from the "0" point. Subjects were given an additional survey to provide suggestions for features that could be improved.

Data Analysis: Descriptive statistics (mean, standard deviation, maximum and minimum values) for clinician and user ratings were analyzed. All statistical analysis was performed using SPSS Version 21 (SPSS Inc, Chicago).

RESULTS and DISCUSSION

Subjects: Of the 13 subjects enrolled in the study, 9 were male and 4 were female. The average age (± standard deviation) of the subjects was 36 ± 19.9 years. Subjects reported a wide range of disabilities, including spina bifida, cerebral palsy, leukodystrophy, multiple sclerosis, and lower limb amputation. The majority of subjects (69.2%) reported the onset of their disability at birth. The remaining subjects reported an average onset (± standard deviation) of 6.75 ± 3.5 years. The majority of the subjects were manual chair users (46.1%). However, a wide variety of WMD types were seen in the subject population, with 15.4% using a power chair, 7.7% using a scooter, and 15.4% using a walker or cane. Two subjects used a combination of assistive devices (e.g. cane or walker and a manual wheelchair for long distance mobility).

WST and User Satisfaction Results: For one user, the RoTrike malfunctioned and was unable to be repaired. Therefore, all RoTrike performance data included the scores for 12 subjects (Tables 1-3).

Table 1: WST performance scores for RoScooter and RoTrike performance during mobility tasks

	RoScooter Average	***RoTrike Average***
Rolls forward 32 feet	2.0 ±0.0	2.0 ±0.0
Rolls backwards 32 feet	1.8 ±0.5	1.8 ±0.4
Turns 90° while moving forward	1.8 ±0.6	2.0 ±0.0
Turns 90° while moving backwards	1.8 ±0.6	1.8 ±0.4
Turns in place 180°	1.8 ±0.4	2.0 ±0.0
Maneuvers 1.6 feet sideways	2.0 ±0.0	2.0 ±0.0
Opens and passes through a hinged door	1.8 ±0.5	2.0 ±0.0
Reaches an object overhead	1.8 ±0.6	2.0 ±0.0
Picks up an object from the ground	1.4 ±0.9	1.4 ±0.8
Relieves weight from buttock	1.3 ±0.9	1.7 ±0.5
Transfers to and from a bench	1.5 ±0.7	1.8 ±0.6
Rolls forward 265 feet	1.8 ±0.6	1.8 ±0.6
Ascends a 6° ramp	0.9 ±0.6	1.0 ±0.6
Descends a 6° ramp	1.8 ±0.6	1.8 ±0.4
Rolls over carpet	2.0 ±0.0	2.0 ±0.0
Moves over small gap	2.0 ±0.0	1.9 ±0.3
Ascends a low curb	2.0 ±0.0	2.0 ±0.0
Descends a low curb	2.0 ±0.0	2.0 ±0.0
Maneuvers in and out of elevator	1.8 ±0.6	1.6 ±0.6
Adjust seat/lever	2.0 ±0.0	2.0 ±0.0
Washes hands at sink	1.0 ±0.0	1.0 ±0.0

Table 2: User ratings for RoScooter and RoTrike performance during mobility tasks

	RoScooter Average	***RoTrike Average***
1. Forward movement	7.9 ±2.8	7.3 ±2.3
2. Backward movement	7.1 ±2.8	5.6 ±3.2
3. 90° turn forward	7.4 ±2.9	5.6 ±3.0
4. 90° turn backwards	6.4 ±3.5	4.6 ±3.0
5. 180° turn in tight space	5.5 ±3.4	4.5 ±2.7
6. Moving sideways next to object	6.1 ±3.0	6.2 ± 2.7
7. Opening, going through, and closing a door	6.0 ±3.2	4.7 ±2.9
8. Reaching up overhead	8.0 ±2.1	6.6 ±2.3
9. Picking something up off the ground	5.1 ±3.5	4.4 ±3.2
10. Maneuvering in an elevator	6.1 ±3.1	4.7 ±2.7
11. Relieving the weight from your buttocks	6.3 ±3.5	6.8 ±3.4
12. Transfer from	6.5 ±3.6	6.0 ±3.0
13. Transfer into	6.9 ±3.1	5.7 ±3.5
14. Application of parking brake	7.1 ±3.6	8.9 ±2.0
15. Forward motion for long distance	7.7 ±2.3	7.4 ±2.0
16. Moving up steep incline	4.0 ±2.6	3.1 ±2.3
17. Moving down a steep incline	6.1±4.0	6.7 ±2.9
18. Moving across a moderately steep slope	5.3 ±3.1	3.8 ±3.2
19. Moving across a thick carpet	7.1 ±2.6	6.2 ±3.4
20. Moving over a pot hole	7.1 ±2.4	6.6 ±2.5
21. Moving over a small obstacle	7.7 ±2.3	7.1±2.7
22. Moving down from a 2-3 inch curb	6.4 ±2.8	5.7 ±2.3
23. Sudden stop	7.6 ±3.4	7.5 ±2.8
24. Washing hands at sink	5.4 ±3.8	4.4 ±2.4
25. Ease of adjusting lever	NA	8.1 ±2.1
26.How much easier than current WMD	4.8 ±3.0	4.7 ±2.9

Table 3: Average, maximum, and minimum overall user ratings for RoScooter and RoTrike

	RoScooter			**RoTrike**		
	Average	*Max*	*Min*	*Average*	*Max*	*Min*
Appearance	6.5 ±2.5	10.0	3.4	6.4 ±3.0	10.0	1.0
Stability	7.1 ±2.3	10.0	4.4	6.2 ±2.9	10.0	0.4
Safety	6.9 ±2.7	10.0	2.2	5.7 ±3.1	10.0	0.4
Comfort	6.8 ±3.2	10.0	1.0	5.9 ±2.6	9.6	0.4
Ease of use	7.0 ±3.3	10.0	1.0	4.7 ±1.8	6.6	0.4
Likelihood to replace	3.3±2.8	8.5	0.0	1.9 ±1.8	5.0	0.0
Likelihood to supplement	3.8±3.2	9.0	0.0	2.6 ±2.5	8.1	0.0

Open-Ended Survey Responses and Comments: The majority of users agreed that the target population for the RoScooter and RoTrike would have some sort of mobility impairment, have good upper body strength, have higher cognitive function, and not be newly injured or disabled. However, there was some discrepancy as to the ideal age of the target population. Some users reported that a younger population would benefit most from the RoTrike and RoScooter. Because younger WMD users generally are in good health and have better upper body strength, they may be better suited to operate the devices. However, other subjects suggested targeting the elderly population. They suggested that the RoScooter and RoTrike may have health benefits for the elderly limited by lower limb impairments.

The majority of subjects thought the handling and maneuverability of both devices was acceptable, reporting that the lever drive systems were fun and easy to use. However, a significant portion of subjects reported that reversing both devices was difficult. To reverse the RoScooter, the user had to spin the lever arm

180 degrees. Because the lever had a large turning radius, the RoScooter was difficult to reverse for subjects with shorter arms. The reversal mechanism on the RoTrike involved reaching down to push on the wheel hand rims, like one would reverse a manual wheelchair. Because of the placement of the wheels and the size of the device, subjects with shorter arms had difficulty reaching the hand rims and reversing effectively without assistance. Overall, the reversal method for the RoScooter was preferred over the method for the RoTrike. Another common suggestion to improve handling would be to add the option of a brake that could be controlled by the left hand on the RoTrike. The RoTrike braking method consisted of a hand brake attached to the right lever arm. Some subjects had significantly more strength in their left hand than their right, making braking difficult. Adding a bilateral brake could appeal to a larger population of potential users.

There was a strong desire by nearly all subjects to have some sort of seating adjustability on both of the ROTA devices. Specifically, users wished to be able to adjust the height of the seat, the distance between the seat and the lever, and the angle of the seat back. For taller individuals, leg room was limited by the positioning of the seat, causing discomfort when operating the ROTA devices. Other subjects had difficulty transferring into and out of the device due to the seat being too high. Additionally, subjects reported that the seat angle was too far forward, making sitting in the device uncomfortable. Being able to adjust various aspects of seating on the RoScooter and RoTrike would make the devices safer and easier to use for a greater number of individuals.

For the most part, users liked the appearance of the RoScooter and RoTrike. However, some users referred to the devices as “bulky”, suggesting that a sleeker appearance may be more appealing. One user recommended having color options for the device, to appeal to younger potential consumers. Another user suggested adding storage space to the device to make it more practical for everyday use.

Other recommendations for device improvement by users is making the device more lightweight for transport and adding a seat belt for safety. Users generally gave the RoScooter higher ratings than the RoTrike, and reported preferring the operation of the RoScooter to the RoTrike. Users gave very low ratings for the likelihood of replacing and likelihood of supplementing from their current WMD (3.3 and 3.8 average ratings for the RoScooter and 1.9 and 2.6 average ratings for the RoTrike, respectively, where 10 indicates very likely to replace). More users said they would prefer ROTA devices to supplement their WMD use as a recreational or exercise device.

CONCLUSION

Based on WMD user feedback, improvements to RoScooter and RoTrike adjustability, maneuverability, seating, and appearance may improve the usability of both devices. Additionally, a clearer target population of users may help make both ROTA devices more marketable. Adding features to the RoScooter and RoTrike to make it more equipped to handle outdoor terrain may also be beneficial. These changes may allow lever-driven devices to be more commonly used.

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