INFLUENCE OF HAND RIM WHEELCHAIR PROPULSION TRAINING IN ADOLESCENT WHEELCHAIR USERS

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ABSTRACT

Participants (n = 10, ages 13-18) completed a total of three propulsion trials on both carpet and tiled surfaces, in their personal wheelchair with a force and moment sensing wheel attached. The first two trials were used as pre-intervention control trials. The third trial was performed after receiving training on proper propulsion mechanics. Peak Resultant Force, Contact Angle, and Stroke Frequency were recorded during all trials for analysis. Results of both the carpet and tile trials indicated that significant increases in Contact Angle and Peak Total Force occurred after training, along with decreases in Stroke Frequency. Overall, the use of short training may help to improve propulsion mechanics in adolescent wheelchair users and decrease risk of upper limb injury.

INTRODUCTION

Manual wheelchair propulsion for daily mobility places significant demands on the upper limbs. Consequently manual wheelchair users experience disproportionately high rates of overuse injury and pain (Ballinger et al., 2000; Curtis et al., 1999) because the upper limbs are repetitively loaded during everyday tasks, like propulsion and transferring (Bayley et al., 1987; Nash et al, 2000). A propulsive stroke with reduced contact angle, high stroke frequency, and elevated forces, have been associated with pain and overuse injuries to the upper limbs (Boninger et al., 2005). Furthermore, the consequences of overuse injuries and pain often impact a manual wheelchair user's functional capacity, which may influence independence and overall QOL. To address the problem, the Consortium for Spinal Cord Medicine has recommended that manual wheelchair users practice long smooth strokes where forces and stroke frequency are minimized to prevent the development of pain and injury (PVACSCI, 2005).

Alarmingly, children who use manual wheelchairs rarely receive formal training on safe and effective wheelchair propulsion techniques. Similar to adults, lack of training can heighten the risk of injury development as a result of poor propulsion technique. While basic skills and resistance training have produced some positive results in pediatric wheelchair users (O'Connell & Barnhart, 1995; Sawatzky et al, 2012), few have examined the influence of manual wheelchair propulsion technique training in this younger population. Furthermore, it remains unclear if children can benefit from training approaches proven successful in adults, like technique and real time visual feedback approaches. For example, with training adults have increased Contact Angle while minimizing Stroke Frequency, and peak forces (Rice et al., 2010, 2013). Therefore it becomes imperative to investigate if younger, more vulnerable wheelchair users can derive similar technique benefits, early on, prior to technique consolidation and the development of upper limb pain and injury.

PURPOSE

The purpose of this study was to test the safety and effectiveness of an instructional video given to younger wheelchair users, that has been previously successful in training adults, to maximize contact angle while minimizing stroke frequency and peak forces at the hand rim (Rice et al., 2010, 2013). The goals of this work are to minimize the risk of upper limb pain and injury development, as well as to determine if younger wheelchair users display stroke mechanics changes that are similar to those seen in adults. Based on previous literature, it was hypothesized that with training, adolescents would behave similarly to adults where Contact Angle increased with reduced Stroke Frequency and peak forces at the hand rim.

METHODS

Participants

The university's institutional review board approved all procedures and informed consent and assent was attained from both the parents and adolescents prior to participation. Inclusion criteria for participation included adolescents, 8-18 years of age who independently propelled a manual wheelchair as their primary mode of mobility. Additionally, all participants were at least 2 years post injury, free of any traumatic upper extremity injury or disability that would be worsened by physical activity. A convenience sample of 10 adolescents (7 male, 3 female, 15.8 ± 1.6 years) recruited from the University of Illinois Youth Wheelchair Basketball Camp volunteered to participate in the study. Participant demographics are described in Table 1.

Equipment

All data collection was performed at the residence hall where the participants were staying for the duration a wheelchair basketball skills camp, located at the University of Illinois, Urbana-Champaign. For data collection, force and moment sensing Clinical SMARTwheels (SmartWheel; Three Rivers Holdings, Mesa, AZ) were fitted bilaterally to replace both wheels on the participants' personal, everyday wheelchairs.

Table 1. Participant demographic information

Participant ID	Age	Gender	Diagnosis	Years Using Chair
1	16	M	SB	16
2	15	M	CMT	9
3	14	F	SCI	10
4	13	F	SB	12
5	15	F	Amp	10
6	17	M	SB	6
7	17	M	SB	15
8	18	M	SCI	3
9	17	M	SCI	10
10	16	M	SB	16

Abbreviations: SB: Spina Bifida, CMT: Charcot-Marie-Tooth Disease, SCI: Spinal Cord Injury, Amp: Amputee

The right SMARTwheel was used for data collection while the left was used as a dummy wheel to match the weight and inertial characteristics. Data from the Clinical SMARTwheel was collected from forces and moments applied to the handrim at a sampling frequency of 240 Hz. While the SMARTwheel is heavier than a standard wheel, it does not alter the feel or setup of a participant's personal chair. Surfaces used for testing were industrial grade carpet and tile, both over 15 m in length to allow participants to complete 5+ steady-state strokes.

Study Design

The intervention consisted of a short training video (5 min) *(Rice et al., 2013),* which allowed for independent viewing. The primary technique objectives were to teach the user to maximize Contact Angle while minimizing Stroke Frequency. For motivation, the video also emphasized the importance of preserving upper limb health to promote independence and quality of life.

Due to the small sample size, participants served as their own control, where trial one consisted of baseline data collection and trial two was a repeat trial. Next, participants were trained and tested again (trial three). Trials one and two were used for comparison to the third, post-intervention trial.

Protocol

After SMARTwheels were attached, participants were instructed to push at a natural, self-selected pace over the carpeted and tiled surfaces. A self-selected speed was chosen deliberately to examine propulsion mechanics occurring at natural and comfortable speeds to maximize safety. Participants completed propulsion over each of these surfaces twice each. Due to the short propulsion distance and submaximal intensity, no recovery time was necessary between the trials. Additionally, researchers provided no feedback or commentary during trials.

After participants completed the first two trials, they were instructed to watch a short, 5 min training video. After completing the video, participants were given the opportunity to ask researchers any questions and briefly practice the new propulsion techniques. During this practice, participants received feedback from researchers on their propulsion mechanics. Immediately after the practice, participants completed the third propulsion trial on both surfaces, at a self-selected pace. Data measures were collected during the entire propulsion period for all trials on each surface.

Data Reduction

The propulsion performance variables selected for analysis were Peak Resultant Force (N), Contact Angle (Deg), and Stroke Frequency (stroke/sec). Additionally, to more accurately examine variable changes, Average Velocity (m/sec) during the trials was examined. All variables were calculated as the mean values of each of the trials.

The key variables for proper propulsion mechanics measurements are Contact Angle, Stoke Frequency, and Peak Resultant Force. Contact Angle is the angle, from contact to release, along the arc of the handrim of the wheel. A larger Contact Angle allows for a reduction in the number of strokes needed to maintain a speed, therefore reducing Stroke Frequency and the number of repetitive motions performed by the upper limbs. Additionally, Peak Resultant Force is the occurrence of the highest vector sum of component forces (Fx, Fy, Fz) applied to the handrim during propulsion. High amounts of force incurred by the shoulder during everyday propulsion contribute to joint damage and overuse injuries (Nyland et al., 2000; Shimada et al., 1998; Vanlandewijck et al., 2001).

Statistical Analysis

All statistical analyses were performed using SPSS (v.20.0 SPSS Inc., Chicago, IL, USA). Differences in normally distributed propulsion variables during the trials were analyzed separately using multiple one-way repeated measures ANOVAs with Bonferroni adjusted post-hoc testing. Variables that violated the Shapiro-Wilk test of normality ($p < 0.05$) were analyzed using nonparametric

Freidman's tests with Bonferroni corrections for pairwise comparisons. To examine possible effects of speed, a repeated measures ANOVA was run on the average velocity of the trials. The criterion to reject the null hypothesis was $p < 0.05$ and sample effect sizes are interpreted as small ($\eta^2 \leq 0.20$), moderate ($\eta^2 \sim 0.50$), and large ($\eta^2 \geq 0.80$). All descriptive statistics are reported as Mean (Standard Deviation) [M(SD)].

RESULTS

Table 2: Carpet propulsion trial results

Performance Variable	**Trial 1 M (SD)**	**Trial 2 M (SD)**	**Trial 3 M (SD)**	**F**	η^2
Parametric Results					
Peak Resultant Force (N)	49.96 (16.67)	51.90 (14.0)	60.99 (18.36)	8.19*	0.48
Contact Angle (Deg)	71.79 (19.22)	78.80 (21.45)	82.66 (16.38)	3.80*	0.30
Nonparametric Results				**X^2**	
Stroke Frequency (stroke/s)	0.82 (0.09)	0.84 (0.10)	0.76 (0.12)	6.05*	0.22

* denotes $p < 0.05$

Table 3: Tile propulsion trial results

Performance Variable	**Trial 1 M (SD)**	**Trial 2 M (SD)**	**Trial 3 M (SD)**	**F**	η^2
Parametric Results					
Contact Angle (Deg)	67.90 (18.68)	73.94 (21.20)	81.28 (18.59)	4.60*	0.38
Nonparametric Results				**X^2**	
Peak Resultant Force (N)	46.95 (15.68)	46.37 (9.90)	59.37 (19.43)	7.40*	0.44
Stroke Frequency (stroke/s)	0.80 (0.08)	0.80 (0.11)	0.72 (0.08)	7.32*	0.19

* denotes $p < 0.05$

All descriptive statistics are reported in Tables 1 and 2. Of the variables from the carpet trials, Stroke Frequency (trial 1: $p < 0.01$) violated the Shapiro-Wilk test of normality and was therefore analyzed using Freidman's tests. Results indicated that during the carpeted trials, after the intervention, statistically significant increases occurred in Peak Resultant Force ($p < 0.01$, $\eta^2 = 0.48$) and Contact Angle (p = 0.04, $\eta^2 = 0.30$) and significant decreases in Stroke Frequency ($p = 0.048$, $\eta^2 = 0.22$). Separate analysis of the average velocity for each of the trials revealed significant differences in speed during the trials, $F(2,18) = 4.83$, $p = 0.02$.

Of the variables from the tile trials, Peak Resultant Force (trial 1: $p = 0.02$) and Stroke Frequency (trial 2: $p < 0.01$) violated the Shapiro-Wilk test of normality and were therefore analyzed using Freidman's tests. Results of the tile trials indicated that after the intervention, statistically significant increases in Contact Angle ($p = 0.02$, $\eta^2 = 0.34$) and Peak Resultant Force ($p = 0.03$, $\eta^2 = 0.44$) and a decrease in Stroke Frequency ($p = 0.03$, $\eta^2 = 0.22$). Separate analysis of the average velocity for each of the trials revealed no significant changes in speed during the tile trials, $F(2,18) = 1.37$, $p = 0.28$.

DISCUSSION

The purpose of this study was to examine the effect of a short training video on the propulsion mechanics used by adolescents to improve technique and reduce risk of injury and pain in the upper limbs. Because few studies have implemented training protocols on younger wheelchair users, another goal of the study was to determine if adolescents would react similarly to adult wheelchair users. Consistent with our hypothesis, changes occurred in participants' propulsion mechanics following the intervention, similar to those found in adult wheelchair users. Specifically, increases in force were found with increased propulsion speed. Additionally, participants demonstrated significant improvements with moderate effect sizes for increased Contact Angle, with decreased in Stroke Frequency.

Participants in this study showed numerous key changes in propulsion mechanics after receiving training and feedback. Specifically, during the carpeted trials, significant increases were observed in Peak Resultant Force. A significant increase Contact Angle occurred, which likely resulted in participant's significant decrease in Stroke Frequency also occurred. Similar to the carpet trials, significant changes were found in Contact Angle, Stroke Frequency, and Peak Resultant Force.

Although previous literature has observed decreases in force application with training, increases in peak forces occurred in this data. These increases are likely due to increases in average speed for each of the trials. Future research may control for speed during propulsion trials, as for this research self-selected speeds were used to maximize the comfort and safety of pediatric participants. Additionally, the use of a larger Contact Angle aids in the prevention of rapid force loading, occurring when contact is made at the top, center of the handrim. With significant increases in Contact Angle reducing the Stroke Frequency, forces are applied over a longer period of time and less frequently to maintain the same velocity (Boninger et al., 2000). This reduction of stroke frequency and forces applied may greatly benefit adolescents in reducing their risk of injury and pain.

While significant changes were found in Contact Angle and Stroke Frequency, the changes might have been modest in comparison to a non-athletic population. Because participants were recruited from a sports camp, their previous experience in athletics may have influenced their everyday propulsion technique. Specifically, experienced manual wheelchair users have been observed to use larger Contact Angles and lower Peak Forces in comparison to non-experienced groups (Robertson et al., 1996; Kotajarvi et al, 2004). It is recommended that future research involving novice adolescents or individuals without athletic training investigate whether larger effects of propulsion training might occur in groups without athletic experience.

LIMITATIONS

As the current study was one of the first to investigate propulsion training in adolescent wheelchair users, some limitations do exist. One of the major limitations was the small sample size available to researchers. This resulted in the lack of a true control group for comparative purposes. Additionally, because no long-term data was collected, it is unknown whether changes in propulsion technique would persist. A final limitation of the study was that, for safety purposes, propulsion velocity of the trial was not controlled and likely influenced the change in Peak Force production. Future research is recommended to address these components and expand on the knowledge of training benefits for pediatric wheelchair users.

CONCLUSION

Overall, it was observed that pediatric wheelchair users did experience significant changes in propulsion mechanics, showing usage of larger Contact Angles and decreases Stroke Frequency. These changes are beneficial to injury and pain prevention of the upper limbs, similar to adult wheelchair users.

REFERENCES

Ballinger, D. A., Rintala, D. H., & Hart, K. A. (2000). The relation of shoulder pain and range-of-motion problems to functional limitations, disability, and perceived health of men with spinal cord injury: a multifaceted longitudinal study. *Archives of Physical Medicine and Rehabilitation*, 81(12), 1575-1581.

Bayley, J. C., Cochran, T. P., & Sledge, C. B. (1987). The weight-bearing shoulder. The *Journal of Bone & Joint Surgery*, 69, 676-678.

Boninger, M. L., Baldwin, M., Cooper, R. A., Koontz, A., & Chan, L. (2000). Manual wheelchair pushrim biomechanics and axle position. *Archives of Physical Medicine and Rehabilitation*, 81(5), 608-613.

Boninger, M. L., Koontz, A. M., Sisto, S. A., Dyson-Hudson, T. A., Chang, M., Price, R., & Cooper, R. A. (2005). Pushrim biomechanics and injury prevention in spinal cord injury: recommendations based on CULP-SCI investigations. *Journal of Rehabilitation Research and Development*, 42(3), 9.

Curtis, K. A., Drysdale, G. A., Lanza, R. D., Kolber, M., Vitolo, R. S., & West, R. (1999). Shoulder pain in wheelchair users with tetraplegia and paraplegia. Archives of physical medicine and rehabilitation, 80(4), 453-457.

Kotajarvi, B. R., Sabick, M. B., An, K., Zhao, K. D., Kaufman, K. R., Basford, J. R. (2004). The effect of seat position on wheelchair propulsion biomechanics. *Journal of Rehabilitation Research & Department*, 41(3B), 403-414.

Nash, M. S., Jacobs, P. L., Mendez, A. J., & Goldberg, R. B. (2000). Circuit resistance training improves the atherogenic lipid profiles of persons with chronic paraplegia. *The Journal of Spinal Cord Medicine,* 24(1), 2-9.

Nyland J, Snouse SL, Anderson M, Kelly T, Sterling JC. Soft tissue injuries to USA paralympians at the 1996 summer games. *Archives of Physical Medicine and Rehabilitation*. 2000; 81(3):368-373.

O'Connell, D. G., & Barnhart, R. (1995). Improvement in wheelchair propulsion in pediatric wheelchair users through resistance training: a pilot study. *Archives of Physical Medicine and Rehabilitation*, 76(4), 368-372.

Paralyzed Veterans of America Consortium for Spinal Cord Medicine (PVACSCI). (2005). Preservation of upper limb function following spinal cord injury: a clinical practice guideline for health-care professionals. *The journal of spinal cord medicine*, 28(5), 434.

Rice, I. M., Pohlig, R. T., Gallagher, J. D., & Boninger, M. L. (2013). Handrim wheelchair propulsion training effect on overground propulsion using biomechanical real-time visual feedback. *Archives of Physical Medicine and Rehabilitation*, 94(2), 256-263.

Rice I, Gagnon D, Gallagher J, Boninger ML. Hand rim wheelchair propulsion training using biomechanical real time visual feedback based on motor learning theory principles. *Journal of Spinal Cord Medicine*. 2010; 1(33):33-43

Robertson, R. N., Boninger, M. L., Cooper, R. A., & Shimada, S. D. (1996). Pushrim forces and joint kinetics during wheelchair propulsion. *Archives of Physical Medicine and Rehabilitation*, 77(9), 856-864.

Sawatzky, B., Rushton, P. W., Denison, I., & McDonald, R. (2012). Wheelchair skills training programme for children: A pilot study. *Australian Occupational Therapy Journal*, 59(1), 2-9.

Shimada SD, Robertson RN, Boninger ML, Cooper RA. Kinematic characterization of wheelchair propulsion. *Journal of Rehabilitation Research and Development*. 1998; 35(2): 210-218.

Vanlandewijck Y, Theisen D, Daly D. Wheelchair propulsion biomechanics. *Sports Medicine*. 2001; 31(5): 339-367.