THE ASSOCIATION BETWEEN HAND ACCELERATION AND WHEELCHAIR PROPULSION KINETICS

Yusheng Yang[1,2], Alicia Koontz[1,2], Rory A. Cooper[1,2], Michael L. Boninger[1,2]
[1]Dept. of Rehab. Science and Technology, University of Pittsburgh, Pittsburgh, PA , USA
[2]Human Engineering Research Laboratories, VA Medical Center, Pittsburgh, PA, USA
E-mail: yuy7@pitt.edu Web: www.herlpitt.org

INTRODUCTION

Previous studies indicate that the prevalence of carpal tunnel system (CTS) among MWUs is approximately 49% (Gellman et al., 1988). A higher rate of force loading on the pushrim during propulsion may lead to the development of CTS (Boninger et al., 1999). Recent studies showed that during wheelchair propulsion, the major cause of a higher rate of impact loading on the pushrim was related to the coupling of the hand to the pushrim (Richter et al., 2002; Yang et al., 2003). Yang et al. (2003) found that a larger difference between the hand speed and the pushrim speed resulted in a higher rate of loading and greater forces imparted to the pushrim as well. To further evaluate the coupling of the hand to the pushrim, we investigated the relationship between hand acceleration immediately before impact with the pushrim and wheelchair propulsion kinetics. We hypothesized that the forces generated during propulsion would be correlated to the hand acceleration prior to contact with the pushrim.

METHODS

Subjects: Thirty-two MWUs (24 men and 8 women) with thoracic or lumbar spinal cord injuries ranging from T1 to L2 provided informed consent prior to participation in the study. Their mean age and years post injury were 42.17±10.71, and 13.46±7.46 years respectively. Their average weight was 79.95 ±17.13 kilograms.

Experimental protocol: Subjects' own personal wheelchairs were fitted bilaterally with SMART^{wheels}, force and torque sensing pushrims, and secured to a dynamometer with a four point tie down system. IRED (infrared emitting diode) markers were placed on the subject's third metacarpalphalangeal joints to record the hand position in a global reference frame via a three-dimensional motion analysis (OPTOTRAK, Northern Digital Inc.). Subjects were instructed to propel at a steady-state speed of 0.9m/s. Propulsion speed was displayed on a 17-inch computer screen placed in front of the subjects. Upon reaching the target speed for one minute, data collection was initiated and continued for 20 seconds. SMART^{wheel} data were collected at 240 Hz and filtered with an 8th order Butterworth low-pass filter, zero lag and 20 Hz cut-off frequency. Afterwards, the kinetic data were linearly interpolated for synchronization with the kinematic data collected at a rate of 60 Hz.

Data analysis: The hand speed $\vec{V} = (V_x, V_y, V_z)$ prior to contact with the pushrim was determined by differentiating the hand position $\vec{P} = (x, y, z)$ in the global reference system. The hand acceleration $\vec{A} = (A_{ht}, A_{hr}, A_{hz})$ prior to contact with the pushrim was determined by differentiating the hand speed $\vec{V}$ in the hand segment reference system, and the hand acceleration (the scalar form of the vector acceleration) was given by: $A_{hand} = \sqrt{A_{ht}^2 + A_{hr}^2 + A_{hz}^2}$. Since previous data have shown that the user's weight is correlated with propulsion forces, the kinetic data were normalized by the subject's weight (Boninger et al., 1999). A coordinate transformation was performed to convert the resulting forces from a global reference frame to a local one with respect to the pushrim where the forces are denoted as radial (F_r), tangential (F_t), and lateral (F_z) forces (Boninger et al., 1999). Five consecutive strokes were used in the data analysis. Peak forces, and the maximum rate of loading (slope of the force curves) were calculated for each stroke. For each parameter, data from all five strokes on the right side were averaged to provide a single kinetic value for the trial.

Statistical Analysis: The Pearson correlation test statistic was used to determine the relationship between the hand acceleration and propulsion kinetic parameters (α=0.05).

RESULTS AND DISCUSSION

Users with a greater mismatch in hand/pushrim speed showed increased hand acceleration prior to contact (r=0.37, p<0.05) (**Table 1**). This increase in hand acceleration just prior to hand contact was an attempt by the users to try and match the pushrim speed. The data analysis also showed that the tangential hand acceleration had a significant positive relationship with the rate of loading on the pushrim (r=0.501, p<0.05), while the radial hand acceleration did not. On average, the tangential acceleration (16.40$\pm$7.24 m/sec^2) was approximately five times the radial component (6.74$\pm$2.65 m/sec^2). This further indicates that before contacting the pushrim, the hand accelerated faster in the tangential direction than in the radial direction in order to match the wheel speed. However, the large acceleration in the tangential direction resulted in a significantly increased rate of loading on the pushrim which has been linked to the development of CTS (Boninger et al., 1999).

SUMMARY

Increased hand acceleration in an effort to compensate for slow hand speed results in a high rate of loading on the pushrim during wheelchair propulsion predisposing the user to injury. Manual wheelchair users may be less prone to wrist injuries if their hand speed prior to contact closely matches the wheel speed.

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Table 1: The correlation between kinetic variables and relative hand acceleration movement in prior to contact.

Kinetic variable (n=32)	Hand acceleration	Tangential hand acceleration	Radial hand acceleration
Relative hand velocity to pushrim	r = 0. 370 p=0. 037*	r = 0. 419 p= 0. 017*	r = -0. 075 p = 0. 682
Peak tangential force	r = 0. 051 p = 0. 784	r = -0. 035 p = 0. 848	r = 0. 263 p = 0. 145
Peak radial force	r = 0. 368 p = 0. 038*	r = 0. 258 p = 0. 155	r = 0. 240 p = 0. 185
Peak total force	r = 0. 433 p = 0. 013*	r = 0. 338 p = 0. 059	r = 0. 176 p = 0. 335
The rate of rise tangential force	r = 0. 589 p = 0. 000*	r = 0. 501 p = 0.004*	r = 0. 052 p = 0. 777
The rate of rise radial force	r = 0. 253 p = 0. 163	r = 0. 183 p = 0. 317	r = 0. 151 p = 0. 409
The rate of rise total force	r = 0. 465 p = 0. 070	r = 0. 360 p = 0. 043*	r = 0. 147 p = 0. 421

* denotes a significant difference (p<0.05)