TEMPORAL CHARACTERISTICS OF REAL-WORLD WHEELCHAIR PROPULSION

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INTRODUCTION

The high prevalence of upper extremity pain and injury reported among individuals with spinal cord injury (SCI) has been attributed to everyday wheelchair propulsion (Boninger et al., 1999). Several researchers have conducted biomechanical studies of wheelchair propulsion to investigate the relationship with pain/injury. However, most of these studies are limited to testing wheelchair users in a controlled laboratory environment with wheelchair ergometers and dynamometers designed to simulate various surfaces and slopes. While these systems have been shown to produce rolling resistances very close to that experienced on an actual surface, users are still confined to testing in an unfamiliar and unrealistic environment. Recently, we conducted a kinetic study of wheelchair propulsion over 'real' surfaces and inclines using a new wireless 3D force and torque measurement system called the SMART^{Wheel} (Three Rivers Holding, Mesa, AZ) (Ebihara et al., 2003). The preliminary analysis provided insight into the forces required to transverse common indoor/outdoor terrain and ramps. The purpose of this study was to expand the analysis to investigate temporal characteristics (e.g., push/recovery time, cycle time, stroke cadence and velocity) as well as distance traveled per stroke.

PROCEDURES

The study took place at the National Veterans Wheelchair Games in Cleveland, Ohio. Eleven (10 men and 1 woman) with a spinal cord injury (ranging from T12 to C6/7) provided written informed consent to participate in this study. The average age and years post injury were 53 and 22 years, respectively. The SMART^{Wheel} was secured to each subject's own wheelchair and he/she was asked to push the wheelchair at a self-selected comfortable speed, over an assortment of surfaces which included shag carpet, indoor tile, hardwood flooring, grass, outdoor concrete tile, smooth, level concrete flooring, and smooth pile carpeting. Subjects were also asked to push up and coast down an outdoor sidewalk with a 5^{o} slope. While coasting down, the subjects were asked to keep pace with a study researcher who walked along their side. The total distances traveled for each surface, ramp up and coast down conditions ranged from 20 to 60 feet. Subjects also popped a wheelie and traveled forward for 10 feet on the smooth, level concrete flooring. Each trial lasted less than 2 minutes with a 5-minute rest break in between. Force and wheelchair position data (via an on-board encoder) from the SMART^{Wheel}'s were recorded at 240 Hz for each trial and post-processed to determine, push time, recovery time, total cycle time, stroke frequency, stroke velocity and distance traveled per stroke. Push time was defined as the amount of time per stroke when force and torque were imparted on the handrim. Thus, recovery time occurred when the hand was off the handrim. Stroke cadence (strokes/second) was calculated as the inverse of the total cycle time.

Peak temporal and distance values were determined for five strokes and averages were computed. Due to occasional technical difficulties with the new instrumentation some trials could not be analyzed and some subjects did not complete all the trials within a condition. The average temporal and distance values were compared across surfaces, wheelie and the two slope conditions (pushing up and coasting down) using a repeated-measures ANOVA test ($\alpha < 0.05$).

RESULTS AND DISCUSSION

Mean temporal and distance data are shown in Table 1. The ANOVA test revealed significant differences between conditions for dependent variables: recovery time (p=0.035), total cycle time (p=0.037), stroke cadence (p=0.028), velocity (p=0.000), and distance (p=0.01). Individual comparisons among the conditions revealed that subjects spent the least amount of time in recovery when wheelie-ing, pushing over grass and up the ramp. Likewise, stroke cadence was higher for these same conditions. The wheelchair users pushed with slower self-selected speeds when propelling over the shag carpet and grass, wheelie-ing and while pushing up the ramp. Distance traveled per stroke was shorter for the wheelie, ramp up, grass, and indoor tile conditions.

High stroke cadence and force during wheelchair propulsion at slow speeds (0.8-1.9 m/s) has been correlated to upper extremity injuries (Boninger et al. 1999). The self-selected speeds in this study fall within this range. In addition, our previous analysis (Ebihara et al. 2003) showed that subjects imparted higher propulsion forces during the same conditions found in this study to involve higher cadences. As these conditions are often performed on a daily basis and are necessary for functional mobility, the risk for developing upper extremity problems is likely higher than if propulsion only occurred on level, even surfaces. Interestingly, users made adjustments in their self-chosen speed and technique, propelling slower and spending less time in recovery during the more challenging conditions (grass, ramp up, wheelie, shag carpet). Chow et al. (2000) also found that wheelchair racers who pushed on a roller system with increasing resistance spent less time in recovery and pushed with a slower self-selected speed when faced with a higher resistance.

REFERENCES

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Table 1: Mean temporal and distance data for each of the test conditions

	A (n=9)	**B (n=10)**	**C (n=11)**	**D (n=11)**	**E (n=11)**	**F (n=11)**	**G (n=10)**	**H (n=11)**	**I (n=11)**	**J (n=9)**
Push time (sec)	0.46	0.66	0.54	0.54	0.62	0.99	0.50	0.63	0.48	0.50
Recovery time (sec)	0.22	0.40	0.51	0.55	0.23	0.69	0.47	0.19	0.51	0.55
Cycle time (sec)	0.68	1.06	1.05	1.09	0.85	1.68	0.97	0.82	0.99	1.05
Cadence (stroke/sec)	1.52	0.97	1.0	0.97	1.2	0.93	1.08	1.31	1.05	1.0
Velocity (m/sec)	0.68	1.04	1.43	1.51	1.01	1.62	1.45	0.75	1.37	1.41
Distance (m)	0.36	0.69	0.73	0.76	0.60	1.79	0.67	0.48	0.61	0.64

Key: A: wheelie 10 feet; B: shag carpet; C: smooth pile carpet; D: smooth level concrete flooring; E: 5° ramp up; F: 5° ramp down; G: outdoor concrete tile; H: grass; I: indoor tile; J: hardwood floor