Start-Up Propulsion Biomechanics Using a Prototype Ergonomic Pushrim

Yusheng Yang, MA, Alicia M. Koontz, PhD, John Kanaly, BS, Michael L. Boninger MD,
Rory A. Cooper, PhD.
Dept. of Rehab. Science and Technology, University of Pittsburgh, Pittsburgh, PA 15206
Human Engineering Research Laboratories, Highland Drive VA Medical Center, Pittsburgh, PA

RESNA 28th Annual Conference - Atlanta, Georgia, 2005

ABSTRACT:

Ergonomic design of a pushrim may improve wheelchair propulsion performance. To evaluate the possible benefits of a prototype ergonomic pushrim design, nine manual wheelchair users conducted a start-up propulsion trial while using their own standard pushrim (SP) and the prototype ergonomic pushrim (NEP). Biomechanics data were compared between start-up and steady-state phases of the trial. The results showed that the NEP minimized hand gripping moments ($p<0.05$) with having similar propulsive power output as the SP at both phases. This finding suggests that using the NEP may reduce potential secondary injuries to the hand.

KEYWORDS: *Steady-state; Acceleration; Propulsion*

BACKGROUND:

The sizes and shapes of commercially available pushrims have been limited to round designs for over 50 years [1]. The smooth low-friction surface and small cross-sectional diameter of a standard pushrim (Figure 1) requires high grip forces in order to keep the hand in contact with the pushrim during propulsion. Many manual wheelchair users (MWUs) use part of the tire in combination with the pushrim to improve their grip. To address the drawbacks of the standard pushrim design, researchers have developed different innovative pushrims, such as the FlexRim (Beneficial Designs, Minden, NV) and the Natural-Fit^{TM} (Three Rivers Holdings, Mesa, AZ). The Natural-Fit^{TM} consists of a larger elliptical-shaped cross-sectional area with a contoured surface connecting the pushrim to the tire for thumb placement. This surface can be coated with a high friction material or textured material for added friction for gripping and the pushrim left smooth underneath for braking. (Figure1).

Figure 1 Goes Here

We have previous investigated forces and torque production using the prototype NEP while propelling under steady-state speed conditions [2]. However, start-up propulsion occurs more frequently than steady-state. Therefore, the purpose of this study was to investigate how the NEP in comparison with the SP during start-up. We were primarily interested in knowing the NEP affects torque generation, power output, speed and acceleration.

METHOD:

Subjects: Nine MWUs (one female and eight male) with spinal cord injuries ranging from T4 to T12 provided informed consent to participate in this study. Their average age and years of injury were 39.6 ± 7.9 and 18.3 ± 8.1 years respectively.

Experiment Protocol: Subjects had a two-week practice period to become accustomed to the NEP. After the practice period, subjects were invited in for testing to push their own wheelchairs, secured to a dynamometer, from rest to their fastest possible speed and maintain the speed for a six second period. The type of pushrim they used first (either NEP or SP) was randomly assigned. The SP was either anodized or vinyl-coated depending on what the subject used on their own wheelchair. The real-time propulsion speed was displayed on a 17-inch computer screen placed in front of the subjects. SMART$^{\text{WheelsTM}}$ (Three Rivers Holdings, Inc., Mesa, AZ), force and torque sensing wheels, were used on both side of wheelchair to measure Fx, Fy, Fz, Mx, My, and Mz forces and moments in a global reference system. A three-dimensional motion analysis system (Northern Digital Inc., Ontario, Canada) was synchronized with the kinetic system to record motion of the upper limbs. Resultant force was calculated as the scalar form of the three-dimensional force vectors. Forces in the plane of the wheel, Fx and Fy, were converted to tangential forces (Ft) and radial forces (Fr) in a pushrim based coordinate system based on the method of point of force application (PFA) [3]. The PFA is a point chosen to be coincident with the third metacarpalphalangeal (MCP) joint in this study, and this point represents the best location where the force is being applied. The PFA method allows an estimate of hand gripping moments by computing the difference between the measured Mz and moments generated about the axle by the applied Ft force (equation 1). From the measured propulsion torque (Mz) and wheel angular velocity (ϖ), the power generation during propulsion could be calculated as shown in equation 2.

Equation 1 and 2 Goes Here

For each stroke, the start and end of the push phase was determined by the presence/absence of forces detected by SMART$^{\text{WheelsTM}}$. The kinetic 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, data were linearly interpolated for synchronization with the kinematic data with collection rate of 60 Hz. *Data analysis:* Since data from both sides were highly correlated ($r^2 = 0.89$; $p < 0.01$), average values of both sides were obtained on all biomechanical parameters over the first six beginning continuous strokes. To discern the strokes involving acceleration phase from the steady-state, the average velocity from each stroke was analyzed by repeated measures ANOVA with post hoc analysis between each stroke. Afterwards, a two-way ANOVA with repeated measures was used to test the main and interaction effects of different pushrims and strokes on all biomechanical parameters. Statistical tests were conducted using SAS (SAS Institute Inc., Cary, NC). Tukey adjustments were used for paired comparisons with an alpha level set at 0.05.

RESULTS:

Table 1 shows the biomechanical parameters for all six strokes for the two different pushrim designs. The average velocity of the first three strokes was significantly different from the last three strokes for both the NEP and SP. Therefore, the first three strokes were considered as the “start-up” strokes. After the fourth stroke, subjects were able to reach a steady-state speed condition with no significant changes in propulsive velocity between strokes four, five and six. During the first three strokes with the NEP, subjects pushed the wheelchair with similar acceleration, speed, power output and propulsion torque in comparison to the SP ($p>0.05$). Less hand gripping moment occurred while using the NEP ($p=0.03$) during start-up. When subjects reached a steady-state speed, the NEP showed no significant differences in average acceleration, speed, and propulsive power, and torque but significantly less hand gripping moments compared to the SP ($p=0.02$). For both start-up and steady-stay phases, subjects using the NEP propelled with larger greater forces ($P<0.05$).

Table 1 Goes Here

DISCUSSION:

Power output in this study was calculated from the measured wheel torque and angular velocity. Our results showed that power output was statistically similar between the two pushrims during start-up and steady-state phases. However, the measured wheel torque is comprised of two parts, tangential force multiplied by the wheel radius and hand gripping moment. The NEP showed greater tangential force with less hand gripping moment while the SP showed less tangential force with greater hand gripping moment. Thus, the added contribution of hand moments contributed to power output and torques for the SP. However, sustained muscle contraction during gripping has been shown to increase the intra-carpal tunnel pressure, which could cause potential injuries to the median nerve [4]. With the NEP, hand gripping moments are reduced without any reduction in power output. This may in turn prevent possible secondary injuries on the hand.

Subjects using the NEP used more non-tangential force to achieve similar power outcome. A possible explanation may be that the subjects in this study were long-time wheelchair users (18.6 years on average) and may have experienced difficultly in adapting to a new pushrim design. Also two-weeks of practice may not have been long enough. With appropriate training users of the NEP may learn to apply lower non-tangential forces during propulsion. A future study with a longer time interval of use and a training program may be needed to elicit the benefits of the new NEP design.

CONCLUSION:

After a two-week practice period of using the NEP, subjects produced similar power and torque during start-up as well as steady-state propulsion in comparison to the SP. With the NEP, hand gripping moments were reduced without any reduction in power output. Subjects also showed larger non-tangential force which may be related to lack of experience and training. Future studies should involve a longitudinal epidemiology study of NEP users to examine the long-term effect of the NEP in preventing overuse injuries.

REFERENCE:

[1] Cooper, RA (1998). *Wheelchair selection and configuration*. New York: Demos

[2] Yang, YS., Koontz, A. M., Kanaly, J., Boninger, M. L., & Cooper, R. A. (2004). *Biomechanical analysis of a new ergonomic wheelchair pushrim.* Paper presented at the Biomedical Enginnering Society Annual Symposium, Tainan, Taiwan

[3] Cooper R.A., Robertson R.N., VanSickle D.P., Boninger M.L., Shimada, S.D. (1996). Projection of the point of force application onto a palmar plane of the hand during wheelchair propulsion. *IEEE Transaction on Rehabilitation Engineering*, 4, 133–142.

[4] Viikari-Juntura E. and Silverstein B. (1999), Role of physical load factors in carpal tunnel syndrome, *Scandinavian Journal of Work, Environment & Health*, 25,163-85.

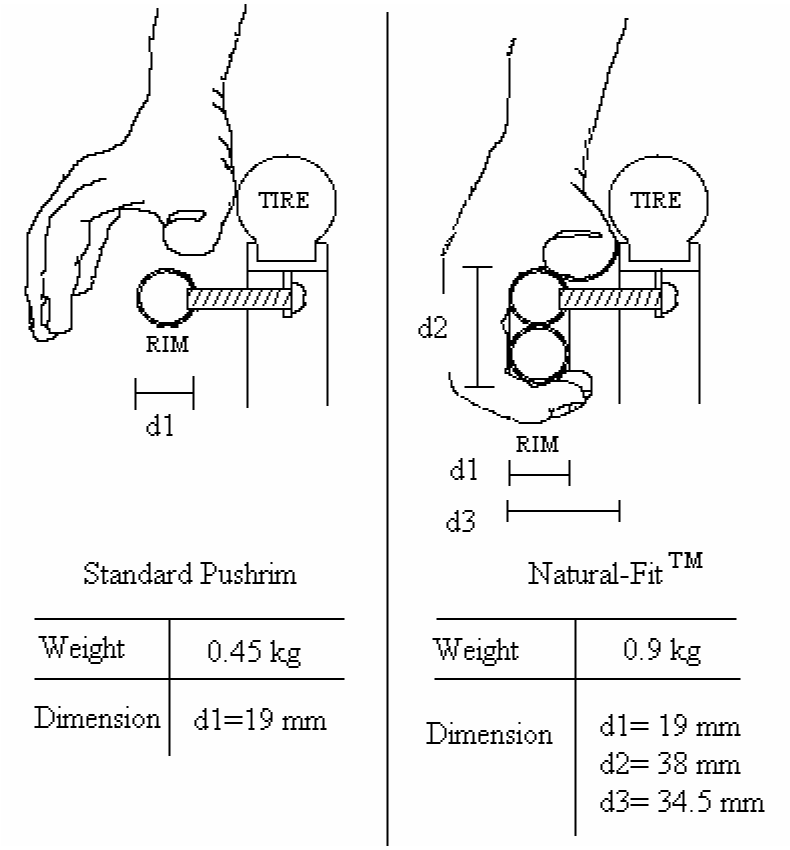
ACKNOWLEDGEMENTS:

This study was supported by National Institutes of Health (NIH 1R43HD39962-01).

YuSheng Yang, Human Engineering Research Labs, VA Pittsburgh Healthcare System, Pittsburgh, PA 15206
Phone: (412) 365-4850, Fax: (412) 365-4858, Email:yuy7@pitt.edu

GRAPHICS PAGE

Figure 1. Standard Pushrim (Left) and Natural-Fit^{TM} (Right)



Weight	0.45 kg
Dimension	d1=19 mm

Weight	0.9 kg
Dimension	d1= 19 mm d2= 38 mm d3= 34.5 mm

Alternative Text Description for Figure 1:
Illustration of the weight and dimension of standard pushrim and Natural-Fit^{TM} prototype ergonomic pushrim.

Equation 1:

$$M_{grip} = M_z - Ft \times R_{rim}$$

where R_{rim} = radius of the pushrim (0.256 m standard rim and 0.267 m for the NEP)

Alternative Text Description for Equation 1:
The hand gripping moment is equal to the difference between the moment measured at the hub and the moment generated by tangential forces applied at the pushrim.

Equation 2:

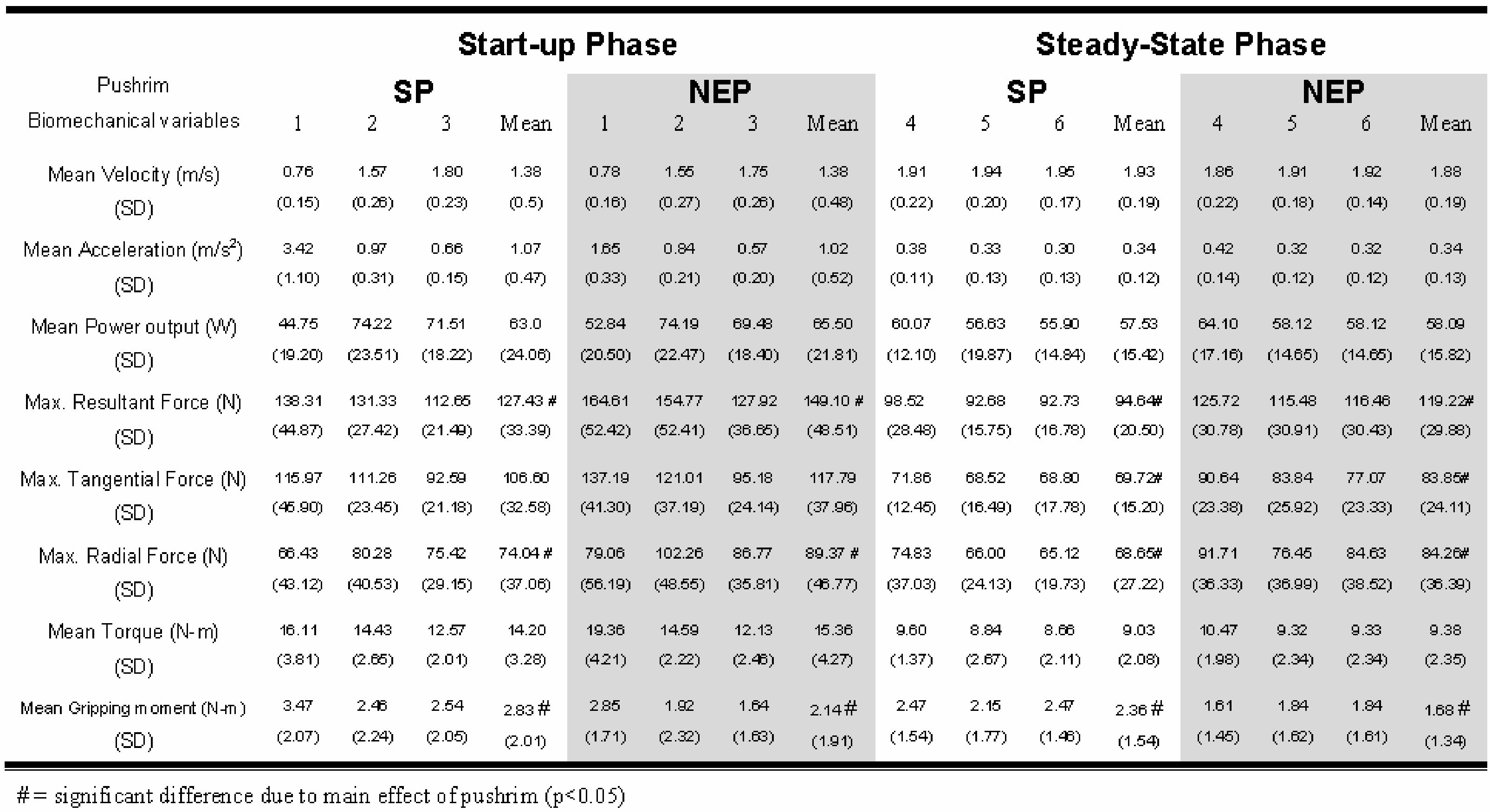
$$P = M_z \times \omega$$

Alternative Text Description for Equation 2:
The power generation during propulsion is equal to the moment measured at the hub multiplied by wheel angular velocity during propulsion.

Table 1. The biomechanical variables during start-up of pushing wheelchair while using the SP and NEP

Alternative Text Description for Table 1

Displays the two-way ANOVA with repeated measures results. No significant difference of averaged propulsive power and torque was found at start-up and steady-speed phase between using the NEP and SP. Peak propulsive force variables (resultant forces, tangential and radial forces) showed a significant larger while using the NEP at start-up and steady-speed phase in comparison with the SP.



	Start-up Phase								Steady-State Phase							
Pushrim	SP				NEP				SP				NEP			
Biomechanical variables	1	2	3	Mean	1	2	3	Mean	4	5	6	Mean	4	5	6	Mean
Mean Velocity (m/s)	0.76	1.57	1.80	1.38	0.78	1.55	1.75	1.38	1.91	1.94	1.95	1.93	1.86	1.91	1.92	1.88
(SD)	(0.15)	(0.26)	(0.23)	(0.5)	(0.16)	(0.27)	(0.26)	(0.48)	(0.22)	(0.20)	(0.17)	(0.19)	(0.22)	(0.18)	(0.14)	(0.19)
Mean Acceleration (m/s^2)	3.42	0.97	0.66	1.07	1.65	0.84	0.57	1.02	0.38	0.33	0.30	0.34	0.42	0.32	0.32	0.34
(SD)	(1.10)	(0.31)	(0.15)	(0.47)	(0.33)	(0.21)	(0.20)	(0.52)	(0.11)	(0.13)	(0.13)	(0.12)	(0.14)	(0.12)	(0.12)	(0.13)
Mean Power output (W)	44.75	74.22	71.51	63.0	52.84	74.19	69.48	65.50	60.07	56.63	55.90	57.53	64.10	58.12	58.12	58.09
(SD)	(19.20)	(23.51)	(18.22)	(24.06)	(20.50)	(22.47)	(18.40)	(21.81)	(12.10)	(19.87)	(14.84)	(15.42)	(17.16)	(14.65)	(14.65)	(15.82)
Max. Resultant Force (N)	138.31	131.33	112.65	127.43 #	164.61	154.77	127.92	149.10 #	98.52	92.68	92.73	94.64#	125.72	115.48	116.46	119.22#
(SD)	(44.87)	(27.42)	(21.49)	(33.39)	(52.42)	(52.41)	(36.65)	(48.51)	(28.48)	(15.75)	(16.78)	(20.50)	(30.78)	(30.91)	(30.43)	(29.88)
Max. Tangential Force (N)	115.97	111.26	92.59	106.60	137.19	121.01	95.18	117.79	71.86	68.52	68.80	69.72#	90.64	83.84	77.07	83.85#
(SD)	(46.90)	(23.45)	(21.18)	(32.58)	(41.30)	(37.19)	(24.14)	(37.96)	(12.45)	(16.49)	(17.78)	(15.20)	(23.38)	(25.92)	(23.33)	(24.11)
Max. Radial Force (N)	66.43	80.28	75.42	74.04 #	79.06	102.26	86.77	89.37 #	74.83	66.00	65.12	68.65#	91.71	76.45	84.63	84.26#
(SD)	(43.12)	(40.53)	(29.15)	(37.06)	(56.19)	(48.55)	(35.81)	(46.77)	(37.03)	(24.13)	(19.73)	(27.22)	(36.33)	(36.99)	(38.52)	(36.39)
Mean Torque (N-m)	16.11	14.43	12.57	14.20	19.36	14.59	12.13	15.36	9.60	8.84	8.66	9.03	10.47	9.32	9.33	9.38
(SD)	(3.81)	(2.65)	(2.01)	(3.28)	(4.21)	(2.22)	(2.46)	(4.27)	(1.37)	(2.67)	(2.11)	(2.08)	(1.98)	(2.34)	(2.34)	(2.35)
Mean Gripping moment (N-m)	3.47	2.46	2.54	2.83 #	2.85	1.92	1.64	2.14 #	2.47	2.15	2.47	2.36 #	1.61	1.84	1.84	1.68 #
(SD)	(2.07)	(2.24)	(2.05)	(2.01)	(1.71)	(2.32)	(1.63)	(1.91)	(1.54)	(1.77)	(1.46)	(1.54)	(1.45)	(1.62)	(1.61)	(1.34)

= significant difference due to main effect of pushrim ($p<0.05$)