Biomechanical Advantages of a 26-inch Rear Wheel

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ABSTRACT
Although the majority of wheelchair users push on 24-inch wheels, a significant number push on larger wheels. This may provide the users with a mechanical advantage due to a larger moment arm. The effects of wheel size on propulsion biomechanics have not been formally studied. The purpose of this study was to compare propulsion biomechanics between 24-inch and 26-inch wheels. Nine wheelchair users pushed on a multigrade treadmill with both wheel sizes while propulsion biomechanics were measured. It was found that a 26-inch wheel led to a larger moment applied to the wheel, an increase in push time and a decrease in push frequency. Use of 26-inch wheels was found to improve propulsion ergonomics and may be an effective strategy for preserving upper-limb health among wheelchair users.

Keywords: wheelchair, propulsion, biomechanics, wheel-size, 26-inch

BACKGROUND

Over 50% of manual wheelchair users develop upper extremity pain and injuries [1]. Carpal Tunnel Syndrome and other wrist injuries have been observed to occur in users that push with a higher cadence (push frequency) [2]. Consequently, clinical guidelines for preserving upper limb health recommend reducing push frequency as one strategy to lower the likelihood of developing overuse injuries [3].

Most adult wheelchair users use 24-inch wheels, but many users push with 25-inch or 26-inch wheels because they feel it is easier to push with them. However, there is no biomechanical evidence to suggest that such an advantage exists. Wheelchair biomechanics research has been limited to using 24-inch wheels because the instrumented test wheels, such as the SmartWheel (Three Rivers), have only been developed as 24-inch wheels. This has resulted in a lack of information on how wheel size affects propulsion biomechanics. Additionally, studies performed using 24-inch instrumented wheels with subjects who typically use larger wheel sizes may not be capturing the true biomechanical characteristics of those individuals.

Mechanically, a larger wheel gives the user a greater mechanical advantage, making it easier to push uphill. When pushing uphill, many wheelchair users will push on the tire instead of the handrim. This provides greater friction, but it also provides a larger moment arm about the wheel, similar to the effect of increasing wheel size. Increasing wheel size is also similar to lowering the seat, since it decreases the distance from the handrim to the shoulder. Lowering the seat has been found to result in an increase in push angle as well as an increase in push time [4]. Larger wheels allow users to sit taller for better reach and are often used during sports, particularly basketball, where they provide a height advantage. Due to the lack of research on wheel size, it is impossible for clinicians to know when, if ever, it is best to prescribe larger wheels to a client.

A propulsiometer instrumented wheel has been developed in the Biomobility Lab that can be attached to any commercially available wheel size, allowing biomechanics studies to be conducted for wheelchairs equipped with varying wheel sizes. All the sensors and support electronics are contained on an outer disk that can be removed and mounted onto the hub of various wheels, shown in Figure 1. The load cell is precalibrated and does not need to be reset for different wheels, making it simple to change wheel sizes during testing.

Figure 1: *The propulsiometer contains a separate instrumentation module that is removable and easily mounted onto any standard wheel size, allowing the propulsiometer size to match that typically used by the test subject.*

RESEARCH QUESTION

The purpose of this study is to determine the effects of a 26-inch wheel on propulsion biomechanics. Studying these effects may provide insight into whether a larger wheel size provides a mechanical advantage, and whether some wheelchair users might benefit from using larger wheels.

METHODS

Participants in this study included manual wheelchair users with full use of their upper extremities. All subjects were required to read and sign an IRB approved consent form before participating in the study (WIRB). The subjects used an adjustable wheelchair equipped with a propulsiometer instrumented test wheel to measure the forces and moments applied to the handrim. The propulsiometer can be used to test propulsion biomechanics for wheels of varying sizes. The wheelchair used in the study was equipped with adjustable length caster forks, allowing the level of the wheelchair to remain constant as rear wheel size was altered. Subjects pushed on a treadmill at level, 3-degree, and 6-degree grades, at individually-selected comfortable pushing speeds for each condition. Subjects pushed for 50 meters on level, 10 meters on a 3-degree incline, and 7.5 meters on a 6-degree incline for both 24-inch and 26-inch wheels. They used the two sizes in a random order, with a rest period in between tests while the wheels were changed. Infrared LED markers were attached to the instrumented test wheel in order to measure kinematics using a 3D active marker motion capture system (Phoenix Technologies). The experimental setup is shown in Figure 2. A dynamic safety system that allows natural propulsion on the treadmill was used to ensure safety of the subjects. All steady-state pushes occurring on each grade were analyzed and used to determine mean and maximum moments applied to the wheel, along with push angle, push frequency, push time, and work generated per push. Average results for the subject group were obtained for each wheel size and grade. The average results were compared using paired samples t-tests and determined to be statistically significant for $p<0.1$. This level of significance was chosen due to the relatively small number of subjects in the study.

Figure 2. *A dynamic wheelchair constraint system has been developed to allow safe wheelchair propulsion testing on a multi-grade treadmill. Treadmill propulsion is an actual rather than simulated propulsion environment, resulting in accurate inertial, resistance and stability performance for any particular individual wheelchair user.*

RESULTS

Nine manual wheelchair users with an average age of 34 years old (sd=10), an average of 12 years wheelchair experience (sd=8), and an average height of 177.5 cm (sd=7.8) participated in the study. Six of the subjects normally used 24-inch wheels, two used 25-inch wheels, and one used 26-inch wheels. The average propulsion velocities selected by the participants were 0.90 m/s (sd=0.20), 0.60 m/s (sd=0.17), and 0.40 m/s (sd=0.14) for the level, 3-degree and 6-degree grades, respectively. As expected, the moment about the wheel increased when using the 26-inch wheels. The average moment increased by 12%, 21%, and 20% for 0, 3, and 6-degree grades, respectively (Figure 3). The resulting handrim biometrics are provided in Table 1. An asterisk denotes statistically significant differences. Both the peak and the mean moments about the wheel were found to be significantly larger for the 26-inch wheel. The increased moment allowed users to generate more work per push when using the 26-inch wheels, with a significant increase found on the 3-degree grade. The results indicate that as wheel size is increased, push time increases and push frequency decreases. The increase in push time was shown to be statistically significant on the level and 3-degree grades. Push frequencies showed a decreasing trend for the 26-inch wheel on all grades, with significant differences found on the 3-degree grade. There was no clear trend in push angle, with the differences all being less than 1.4 degrees. However, there was a small, but statistically significant decrease in push angle on the 3-degree grade.

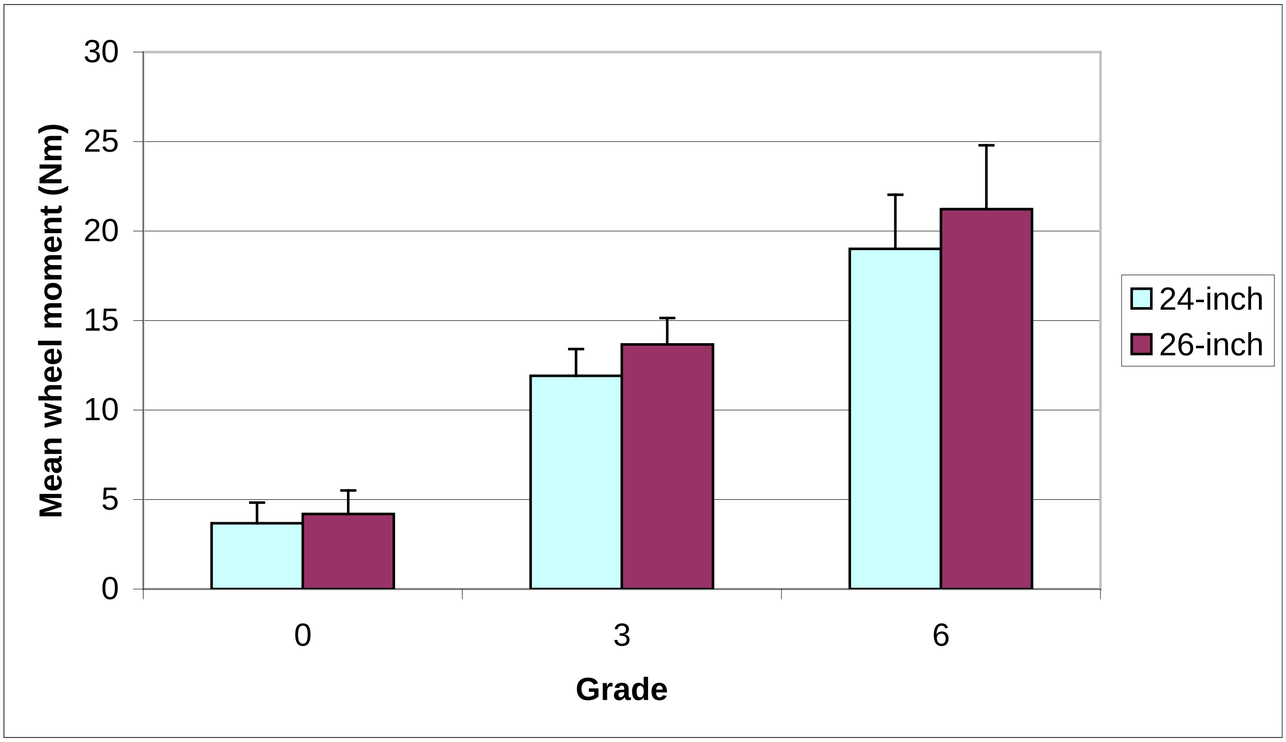

Figure 3. *Plot of mean wheel moments for 24 and 26-inch diameter wheels on level, 3-degree, and 6-degree grade conditions. Bars show average values with standard deviations, and demonstrate the trend of increased moments for greater wheel sizes. All differences were statistically significant.*

Condition	Max Moment (Nm)	Mean Moment (Nm)	Push Time (sec)	Push Frequency (push/sec)	Push Angle (deg)	Work (J)
24-inch (Level)	7.41	3.45	0.55	1.02	93.1	2.95
26-inch (Level)	8.80*	3.87*	0.60*	0.97	94.5	3.22
24-inch (3 deg)	19.37	11.30	0.82	0.94	91.0	13.71
26-inch (3 deg)	22.54*	13.66*	0.86*	0.89*	89.7*	15.77*
24-inch (6 deg)	25.88	17.69	1.22	0.88	77.0	21.06
26-inch (6 deg)	31.22*	21.22*	1.31	0.69	77.6	24.32

Table 1. *Resulting biometrics for 24 and 26-inch diameter wheels on level, 3 degree, and 6 degree grade conditions. Outcomes include the time during which the users pushed on the handrims (Push Time), the push cadence (Push Frequency), the angle through which the users pushed on the handrims (Push Angle), the maximum moment applied to the wheel, the mean moment applied to the wheel, and the work generated per push.*
** = $p<0.10$*

DISCUSSION

This study provides evidence that use of 26-inch wheels may offer biomechanical advantages over the standard 24-inch diameter wheels during propulsion. These advantages are particularly apparent while pushing up an incline, when demand on the user is the greatest. The increased moment on the wheel for the 26-inch wheels provides evidence of a mechanical advantage that was expected for a larger wheel. The increased work per push led to a decreased push frequency. The reduced push frequency provides an ergonomic advantage that may lead to a reduction in repetitive stress injuries [2,3]. It is clear that there are discernible differences between the different wheel sizes. Because of this, it is recommended that further research be performed with a larger subject population in order to thoroughly explore the extent of these differences. It is also suggested that future wheelchair biomechanics studies incorporate wheels of varying sizes, since studies based solely on 24-inch wheels may provide erroneous data on those wheelchair users who typically use larger wheels. These subjects should be tested using their everyday wheel size in order to obtain accurate data on their individual biomechanical demand. Further research on the effects of 26-inch wheels will further quantify the ergonomic advantages of larger wheels, and will allow clinicians to determine when it would be most appropriate to prescribe larger wheels to their clients.

REFERENCES

1) Sie,I.H., Waters,R.L., Adkins,R.H., Gellman,H. (1992) Upper extremity pain in the postrehabilitation spinal cord injured patient. *Arch Phys Med Rehab*, 73(1), 44-48.
2) Baldwin,M.A., Boninger,M.L., Shimada,S., Cooper,R.A., and O'Connor,T.J. (1998) A Relationship between Pushrim Kinetics and Median Nerve Disfunction. *Proc RESNA '98 Ann Con* 378-380.
3) Consortium for Spinal Cord Medicine Clinical Practice Guidelines. (2005) "Preservation of Upper Limb Function Following Spinal Cord Injury: A Clinical Practice Guideline for Health-Care Professionals". PVA Publications.
4) Van der Woude,L.H., Veeger,D., Rozendal,R.H., and Sargeant,T.J. (1989) Seat height in handrim wheelchair propulsion. *J Rehab Res Dev*, 26(4), 31-50.

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