Influence of Tire Type on Wheelchair Coast Down Testing: A Pilot Study

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ABSTRACT

The objective of this study was to compare the relative rolling resistance of four common wheelchair tires and the SmartWheel. Coast down testing was performed with each pair of wheels positioned on a two-drum roller system. Within each weight condition (45.4 kg, 68.1 kg, 90.8 kg), tire type had a notable effect on coast down time. The pneumatic tires had longer coast down times and were less affected by weight increases than the solid tires. Solid tires are used because they require less maintenance than pneumatic tires; however, their relatively short coast down time, and thus theoretically high rolling resistance, should be considered when determining the appropriateness of a given tire.

Keywords: coast down testing; manual wheelchair; rolling resistance; SmartWheel; tire type

BACKGROUND

Proper selection and maintenance of wheelchair tires is key to helping users maximize their wheeling efficiency. The material composition and profile of a wheelchair tire influence rolling resistance and consequently ease of propulsion. In a study of rolling resistance, Sawatzky et al. found the pneumatic tires exhibited a longer coast down distance compared with solid tires [1]. Even at 50% of their recommended inflation pressure, the pneumatic tires rolled significantly farther than the solid tires. A more material-based study conducted by Gordon et al. found that pneumatic tires had a lower rolling resistance force than three distinct solid tires [2].

Despite the known advantages of pneumatic tires, including improved vibration absorption, solid tires are still used for convenience by wheelchair users and researchers. Solid tires are used on the SmartWheel (Three Rivers Holdings, LLC, Mesa, AZ), an instrumented wheelchair wheel used to measure three-dimensional pushrim forces and torques during propulsion. In an ongoing study of wheelchair propulsion in individuals with tetraplegia, participants noted that pushing their wheelchair with the SmartWheels attached was considerably more difficult than pushing with their own wheels. This feedback led to an investigation of the influence of SmartWheel tire type on test results. The objective of this study was to compare the coast down time of the tire used on the SmartWheel to other commonly used wheelchair tires. It was hypothesized that tire type would have a significant influence on coast down time. Without knowing the inertial properties of each wheel, measurements of rolling resistance could not be made. However, coast down testing has been reported to be an acceptable method for comparing the rolling properties of wheelchair tires [1,3].

METHODOLOGY

Five different tire types were tested: Primo V-Trak pneumatic tires (HPPT), Primo Orion pneumatic tires (LPPT), KIK Mako low profile solid tires (KMST), Cheng Shin full profile tires

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with solid inserts (CSSI), and the Alshin solid tires used on the SmartWheel (SWAT). Each tire remained on its own wheel; therefore, five different sets of wheels were tested (Figure 1).

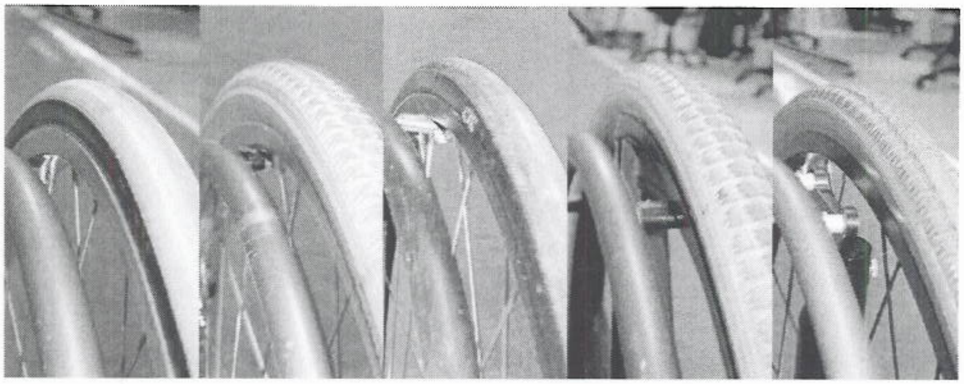

Figure 1. Tires tested in the study. From left to right: Primo V-Trak (HPPT), Primo Orion (LPPT), KIK Mako (KMST), Cheng Shin with solid insert (CSSI), and SmartWheel Alshin (SWAT).

All wheels were 24 inches in diameter and mounted on Sunrims (SW600 or DW600) with radial spokes, with the exception of the Cheng Shin solid insert tires, which were mounted on 8-spoke plastic mag wheels. Both pneumatic tires were inflated to the manufacturer's recommended pressure. Table 1 shows the model, type, mass, and recommended pressure of each wheel.

Table 1. Wheel properties

Tire	Type / profile	Wheel Mass (kg)	Recommended Pressure (pounds/in^2)
Primo V-Trak	Pneumatic / low	1.73	100 psi
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SmartWheel-Alshin	Solid / full	5.4	-

Each set of wheels was placed on a Quickie GPV rigid frame wheelchair (weight: 8.99 kg, width: 45.5 cm, wheelbase: 36 cm). The wheelchair was secured over a two-drum roller system such that the rear wheels rested on separate drums, allowing for independent wheel rotation. Barbell plates were added to the seat of the wheelchair to simulate the weight of a user. Three different weight conditions were tested: 45.4 kg, 68.1 kg, and 90.8 kg. A calibrated force plate (Bertec Corporation, Columbus, OH) was used to determine the mass supported by each rear wheel. Spherical reflective markers were placed on the axle and pushrim of each wheel as well as on the frame of the wheelchair and on the center of the top weight.

Both wheels were spun to a tangential velocity of at least 1.79 m/s. Velocity was measured with an encoder fitted to the surface of each drum. Once the speed was reached, rotational force was discontinued and the wheels were allowed to coast down to a complete stop. Ten trials were performed for each tire under each weight condition (150 trials total). During each trial, the movements of the reflective markers were recorded at 120 Hz using a Vicon motion capture system (Vicon, Oxford, UK). Markers on the frame and weights were checked to ensure consistent weight position (within 1 cm) for all coast down trials and force plate measurements.

Data Analysis

Due to slight side to side differences in the roller system, wheel camber, wheelchair alignment, and weight distribution, evaluation of tire performance was determined from marker trajectories collected from the left wheel (camber: 4 degrees) only. Using markers on the hub (Hub_{xyz}) and pushrim (Rim_{xyz}), the rotation of the wheel between each time point was determined from the law of cosines.

Equation 1:

$$\theta = \cos^{-1}\left(\frac{A \cdot B}{\|A\|\|B\|}\right)$$

where: $A = Rim_{xyz} - Hub_{xyz}$ *at time point (i)*
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Angular velocity was determined by dividing the change in angle by the change in time for each frame. The coast down time (CDT) was defined as the time period, in seconds, over which the wheel decelerated from 300.00 deg/sec to 100.00 deg/sec (approximately 1.60 m/s to 0.53 m/s). All CDTs were normalized to the static weight of the system including the SmartWheel to account for the different wheel weights. Using the weight on the left rear wheel, as determined by force plate measurements, the normalization was conducted as follows:

Equation 2:
Normalized CDT of Tire X = (system mass with Tire X / system mass with SW)

The weight normalization performed on the CDTs was intended to account for differences in rolling resistance force and not the inertia of the wheel. Future testing may involve measuring the moment of inertia of the wheels and the roller system, allowing for better data comparison and calculations of rolling resistance force. A repeated measures ANOVA was performed to determine whether the difference between the weight conditions was significant in CDT. Significance was set at $p < 0.025$ to accommodate the multiple comparisons.

RESULTS

Table 2 shows the mean coast down times and weight-normalized mean coast down times for all tires. The difference in CDT were significant between the two lower weight conditions ($p = 0.0007$) and the two higher weight conditions ($p = 0.0057$). Figure 2 shows the relative differences in the weight-normalized mean CDTs. All tires experienced a significantly ($p = 0.0102$) greater drop in CDT between 45.4 kg and 68.1 kg (26.4 ± 2.0% pneumatic; 35.3 ± 9.7% solid) than between 68.1 kg and 90.8 kg (6.1 ± 2.4% pneumatic; 25.5 ± 6.2% solid).

Table 2. Raw and nomalized coast down times

Tire	Weight Condition (kg)	Left Side System Weight (kg)	Raw CDT (sec)	Normalization to SW factor	Normalized CDT (sec)
HPPT	45.50	18.57	16.78 ± .15	0.84	14.10 ± .13
	68.10	27.55	12.02 ± .21	0.88	10.57 ± .19
	90.80	38.57	11.11 ± .26	0.91	10.11 ± .23
LPPT	45.50	18.88	14.87 ± .10	0.85	12.64 ± .08
	68.10	27.86	10.24 ± .24	0.89	9.12 ± .21
	90.80	38.88	9.14 ± .23	0.92	8.41 ± .21
KMST	45.50	18.98	12.32 ± .09	0.85	10.47 ± .08
	68.10	27.96	8.81 ± .12	0.90	7.93 ± .11
	90.80	38.98	7.03 ± .14	0.92	6.47 ± .13
CSSI	45.50	19.69	7.37 ± .11	0.89	6.56 ± .09
	68.10	28.67	4.10 ± .12	0.92	3.78 ± .11
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SWAT	45.50	22.24	4.89 ± .12	1.00	4.89 ± .12
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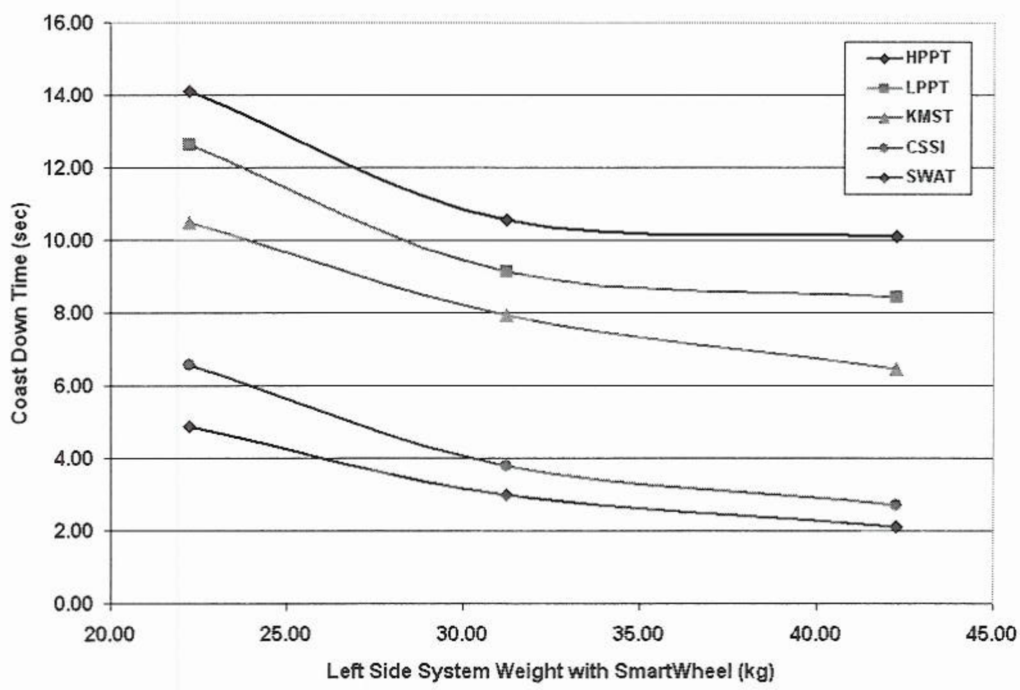

Figure 2: Weight-normalized coast down times.

DISCUSSION

The weight-normalized CDTs demonstrated the significant effect on rolling. By inspection, consistent with previously published findings [1], the pneumatic tires exhibited lower resistance to rolling than solid tires. In addition, the high pressure (100 psi) Primo V-Trak tire rolled longer than the lower pressure (75 psi) Primo Orion tire. The solid tires experienced larger decreases in

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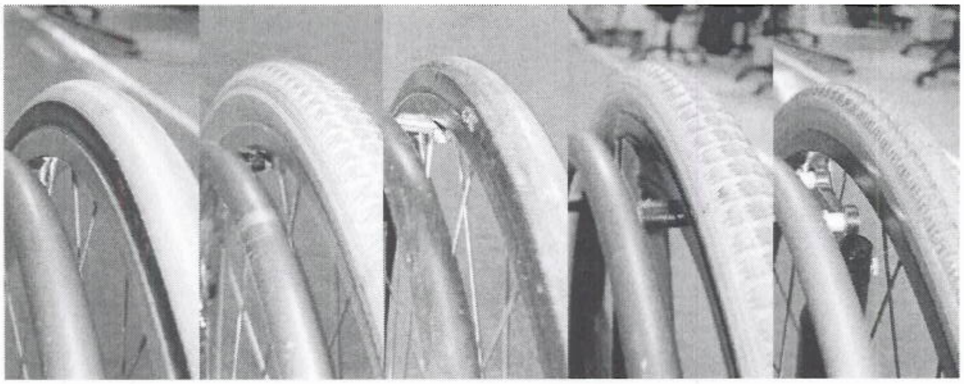

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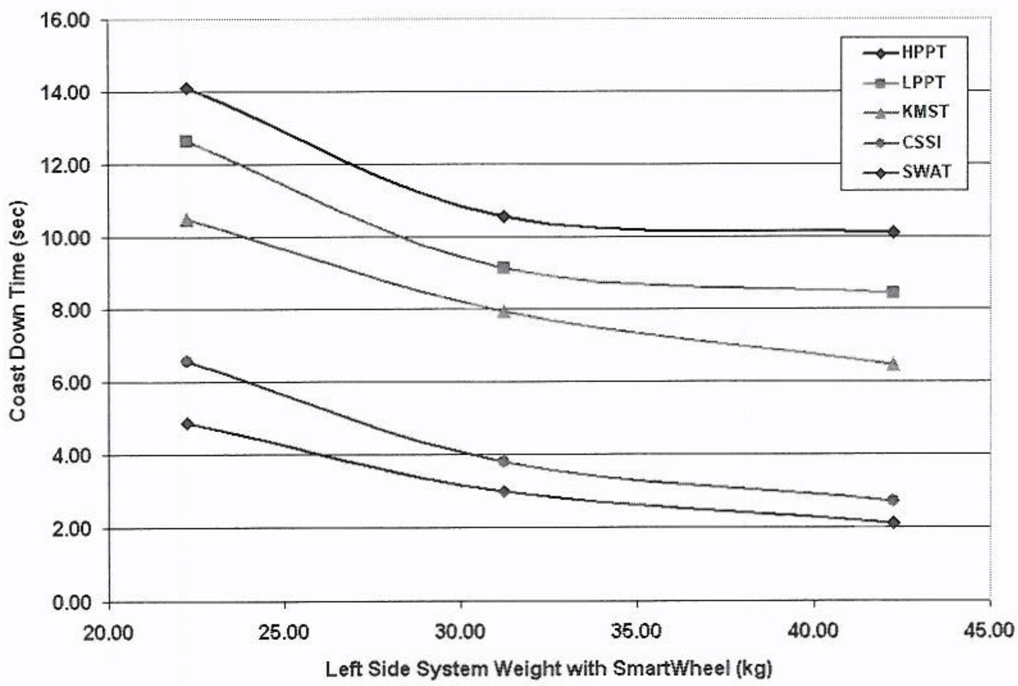

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The weight-normalized CDTs demonstrated the significant effect on rolling. By inspection, consistent with previously published findings [1], the pneumatic tires exhibited lower resistance to rolling than solid tires. In addition, the high pressure (100 psi) Primo V-Trak tire rolled longer than the lower pressure (75 psi) Primo Orion tire. The solid tires experienced larger decreases in

CDT between the three weight conditions, particularly between 68.1 kg and 90.8 kg. Gordon et al. showed that polyurethane foam solid tires exhibit an exponential increase in rolling resistance with increased load whereas pneumatic tires exhibit a more linear increase. Molded polyisoprene solid tires experienced a more linear increase; however, they had the largest rolling resistance force for smaller loads (< 150 lbs). The larger increases in force are due to greater energy loss within the solid tire material [2]. The relationship between rolling resistance force, applied load, and tire type is particularly relevant to wheelchair users. Heavier individuals are at a greater disadvantage than lighter individuals when propelling wheels with solid tires. The larger rolling resistance experienced by heavier users may result in higher joint forces during propulsion and thus a greater risk of injury.

In terms of research applications, solid tires may effect measurements of wheelchair biomechanics. The SmartWheel is used to measure the forces and moments applied by the user under normal conditions. However, for individuals who use pneumatic tires, the solid tires impose an abnormal amount of rolling resistance which may affect the validity of the measurements. While we cannot decrease the weight of the SmartWheel, we can choose a tire that allows users to propel as they would with their own wheels.

Based on the sample of one tire per type, it was difficult to assess the effects of tire profile on coast down. Within the solid and pneumatic groups, the low profile tires had longer CDTs than the full profile tires; however, these differences are also related to tire hardness. This was apparent in the CDTs of the SmartWheel Alshin tire and the Cheng Shin solid insert tire. Both tires have similar profile and tread design, but their CDTs were different across each weight condition. In contrast, the low profile KIK Mako solid tire had notably longer CDTs than both wheels. Across the three weight conditions, the mean CDT of the KIK Mako was 2.03 times longer than the Cheng Shin and 2.63 times longer than the SmartWheel Alshin. The mass and CDT of the KIK Mako tire was most similar to that of the full profile Primo Orion pneumatic tire. It is assumed that the low profile nature and relatively high durometer of the tire make the KIK Mako preferable to the other solid tires. Users who want the benefits of low maintenance solid tires without sacrificing much in terms of rolling efficiency should consider the KIK Mako.

Limitations

No direct measurements of rolling resistance were made in this study. Likewise, no measurements were made of moment of inertia, coefficient of rolling friction, or tire deformation, thus precluding any calculation of rolling resistance. Lastly, due to lack of available resources, the wheels used in this study were not controlled. Future testing will control for the rim, hub and tire tread design of each wheel.

CONCLUSIONS

The high pressure, low profile pneumatic tire exhibited a longer coast down time than the lower pressure pneumatic and all three solid tires. Tire selection should be a serious consideration for clinicians and wheelchair users. Researchers should also consider the additional rolling resistance of solid tires and how their usage may affect study results.

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KESSLER MEDICAL REHABILITATION RESEARCH AND EDUCATION CENTER

THE HENRY H. KESSLER FOUNDATION

INTRODUCTION

Selection of wheelchair tire type influences rolling resistance and consequently ease of propulsion. Sawatzky et al. found the pneumatic tires exhibited a longer coast down distance compared with solid tires [1]. Despite the known advantages of pneumatic tires, solid tires are used by wheelchair users and researchers as a low maintenance, flat free alternative. In an ongoing study of wheelchair propulsion, participants noted that pushing their wheelchair with a pair of SmartWheels (Three Rivers Holdings, LLC, Mesa, AZ), instrumented pushrims used to measure three-dimensional pushrim forces and torques, was considerably more difficult than pushing with their own wheels. The SmartWheel uses a solid, high profile tire instead of the pneumatic tires used by the participants. This led to an investigation of the influence of tire type on test results.

The objective of this study was to compare the relative rolling resistance of four common wheelchair tires and the SmartWheel using coast-down testing. It was hypothesized that tire type would have a significant influence on coast down time. Without knowing the inertial properties of each wheel, measurements of rolling resistance could not be made; however, coast down testing is an acceptable method for comparing the rolling properties of wheelchair tires [1,3].

TIRES / WHEELS

Five tire types were tested:
1) Primo V-Trak pneumatic tires (HPPT)
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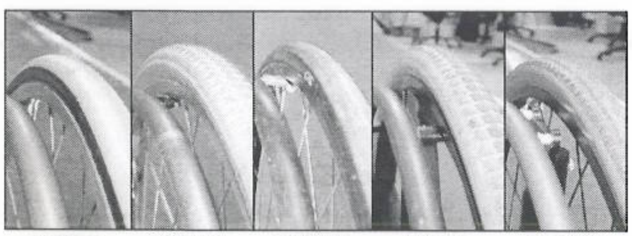

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DATA COLLECTION & ANALYSIS

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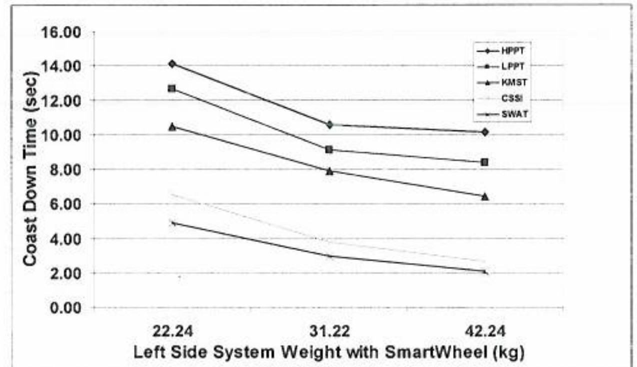

DISCUSSION

For wheelchair users:

- The pneumatic tires exhibited a greater CDT and therefore lower resistance to rolling than solid tires.
- The high pressure (100 psi) Primo V-Trak tire rolled longer than the lower pressure (75 psi) Primo Orion tire.
- The solid tires experienced larger decreases in CDT between the three weight conditions, particularly between 68.1 kg and 90.8 kg due to greater energy loss within the solid tire material [2].
- Heavier individuals are at a greater disadvantage than lighter individuals when propelling wheels with solid tires.
- Users who want the benefits of low maintenance solid tires without sacrificing much in terms of rolling efficiency should consider the KIK Mako.

For researchers:

Solid tires may effect measurements of wheelchair biomechanics. For individuals who use pneumatic tires, the solid tires used on the SmartWheel impose an abnormal amount of rolling resistance which may affect the validity of "real world" measurements. While we cannot decrease the weight of the SmartWheel, we can choose a tire that allows users to propel as they would with their own wheels.

Future research

Investigate the influence of tire type on the kinematics and kinetics of wheelchair propulsion.

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