Effects of incremental mass changes on wheelchair motion using robotic tester

Rehabilitation Engineering & Applied Research

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Why does mass matter?

Manual wheelchair (MWC) designs should be optimized to reduce strain on the upper extremities. Several factors have been identified: wheel selection[1], shoulder-to-axle position[2], and weight distribution[3] have all been correlated to performance differences, but adding up to 10 kg to the chair has had little effect on human propulsion metrics[1,2]. Yet, differences of less than 3 kg separate the "standard" and "ultra-lightweight" wheelchair categories, with an implicit message that mass reflects performance. Why?

This study investigated mechanical performance differences of a wheelchair with incremental mass added to the frame, with disparate weight placement locations.

Experimental design

Five configurations were used:

Config. Name	Added Mass	Placement	Weight Dist. (% over axle)
0A	+0 kg	Axle	71.9%
2A	+2 kg	Axle	72.0%
4A	+4 kg	Axle	72.0%
2F	+2 kg	Footrest	68.7%
4F	+4 kg	Footrest	65.7%

A Dibond metal sheet was fastened under the wheelchair seat to support additional mass at the axle (Figure 1).

Figure 1. (Left) Dibond platform to fasten weights. (Mid) Loaded with +4 kg on the axle. (Right) +4 kg on the footrest.

This study utilized:

- Ultra-lightweight wheelchair frame (Quickie GT)
- Pneumatic drive wheels (24 x 1" Primo Orion, 75 psi)
- Solid casters (5 x 1" Primo, polyurethane).

Acknowledgements

This study was supported via internal funding from the Rehabilitation Engineering and Applied Research Lab.

Experimental apparatus – The AMPS

The Anatomical Model Propulsion System (AMPS[4], Figure 2) was used to test each MWC configuration. The AMPS applies a standardized torque profile (Figure 3) on each wheel simultaneously, and uses clutches to coast between each push.

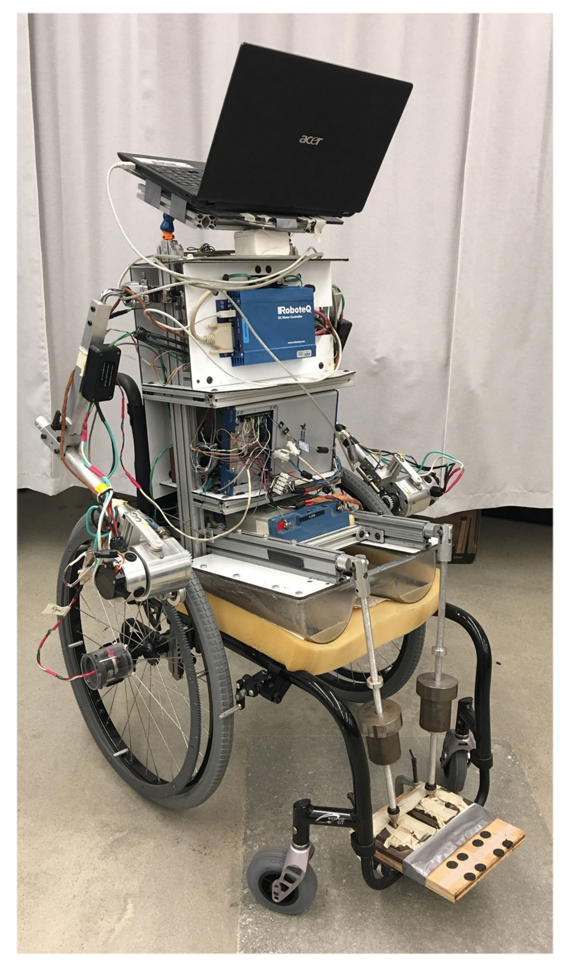
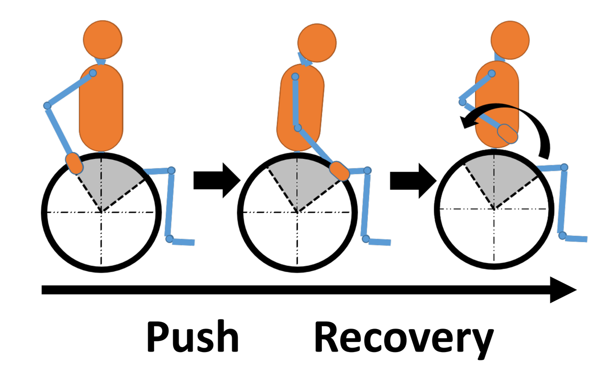
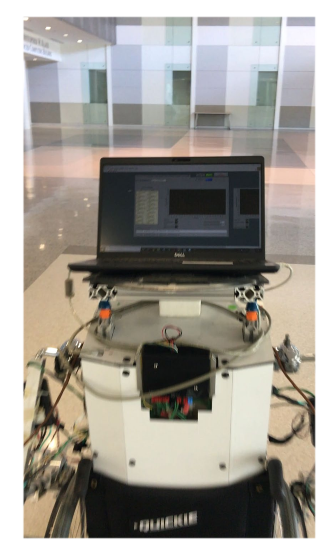


Figure 2. The AMPS robot.

Instrumentation:
- High-powered DC motors
- Wheel-mounted encoders
- Torque (current) sensors
- Motor encoders





Video 1: AMPS in motion

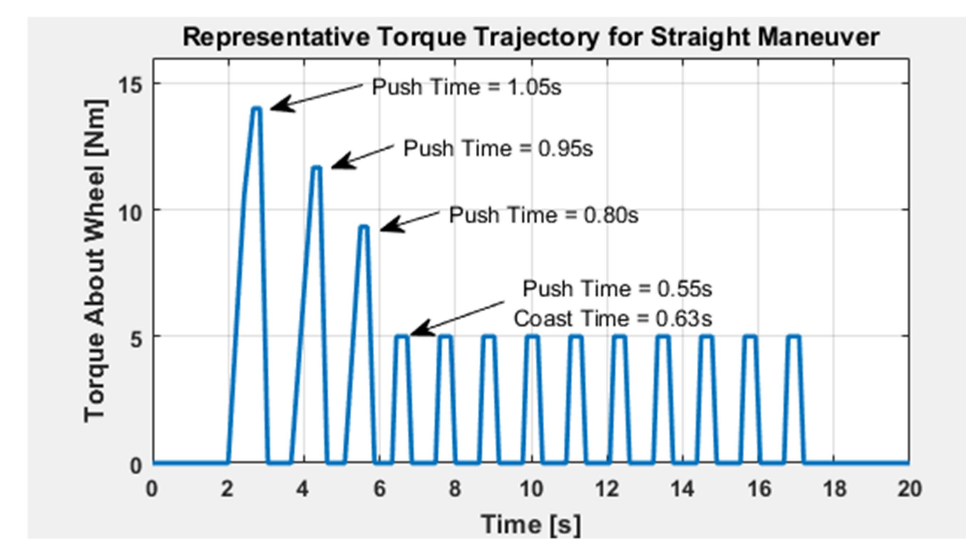


Figure 3. The standardized torque trajectory.

The torque trajectory (Figure 3) was designed using features from human propulsion studies using instrumented torque-sensing push rims (e.g. SmartWheel and OptiPush).

Results – Propulsion cost and distance differences

$$Propulsion\ Cost = \frac{\int_{t_i}^{t_f} (wheel\ torque_{L,R} * wheel\ speed_{L,R})\ dt}{distance\ traveled\ by\ CoM}$$

Config.	Total Propulsion Cost (J/m) Mean	StDev	Effect Size	% Change
0A	13.06	0.17	-	-
2A	13.15	0.14	0.53	+0.65%
4A	13.21	0.16	0.88	+1.13%
2F	13.23	0.18	0.93	+1.25%
4F	13.37	0.17	1.76	+2.34%

Config.	Total Distance Traveled (m) Mean	StDev	Effect Size	% Change
0A	11.37	0.37	-	-
2A	10.85	0.45	1.27	-4.61%
4A	10.58	0.40	2.03	-6.90%
2F	11.00	0.44	0.91	-3.24%
4F	10.44	0.45	2.27	-8.21%

Propulsion cost[4] is the work supplied by the motors over the displacement of the center of mass (CoM). The distance, found by integrating the wheel encoder signals, shows how far each configuration rolls, given an identical torque input.

A lower cost and/or a greater distance traveled are the ideal outcomes.

Relating to needs of wheelchair users

The wheelchair is reaccelerated every single push, and greater mass needs greater force for the same acceleration.

	Frame Mass	With AMPS
Quickie GT	13.1 kg	93.1 kg
+4 kg	17.1 kg	97.1 kg
% Diff	26%	4%

With only a 4% system mass increase, how much change can we expect to see?

The 1-2% cost increases imply that mass can reduce MWC performance, but the effect can be minimized by shifting the weight closer to the drive wheel axle – accomplished by moving the axle forward or sliding the seat back.

Significance of the results

Under the same torque application:

- Heavier MWCs used more energy per meter (< 2.34%)
- Shifting the weight rearward mitigated the effect (< 1.13%)

Energy losses increase with higher loads on the casters[5].

- The 6% change in weight distribution actually affects caster loading more than the +4 kg.

System dynamics will be examined in future work (Figure 4).

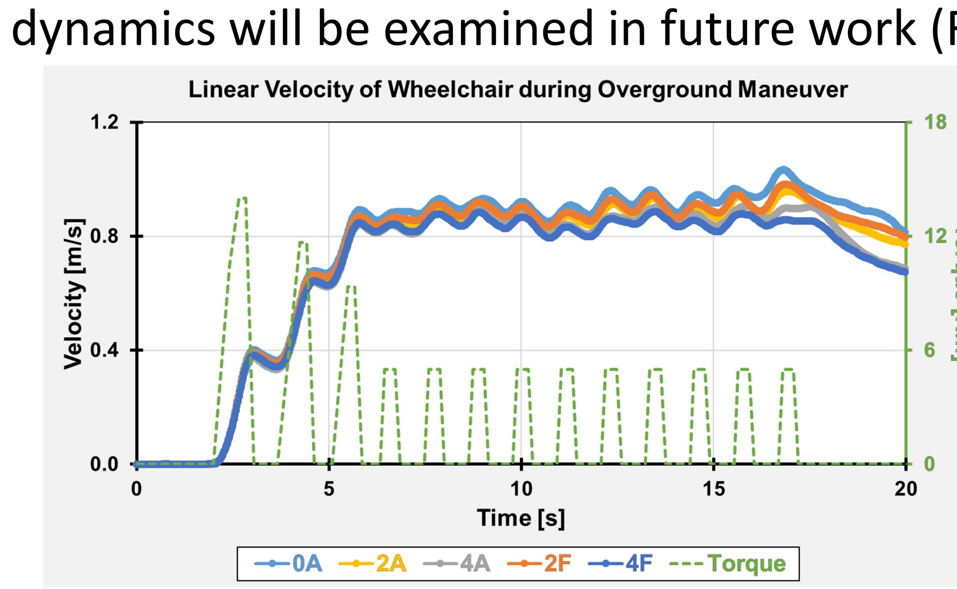


Figure 4. Representative velocities for each configuration during the overground maneuver.

[1] de Groot, S., et. al. *Med Eng Phys*, 2013. **35**(10): p. 1476-82.
[2] Lin, J.T. and S. Sprigle. *Disabil Rehabil Assist Technol*, 2020. **15**(3): p. 328-335.
[3] Cowan, R. E., et. al. *Arch Phys Med Rehabil*, 2009. **90**(7): p. 1076-1083.
[4] Sprigle, S. and M. Huang. *J Rehabil Assist Technol Eng*, 2020. **7**: p. 1-14.
[5] Sprigle, S., M. Huang, and J. Misch. *Assist Technol*, 2019. p. 1-13.

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