Rehabilitation
Engineering &
Applied
Research

The Impact of Wheelchair Weight Distribution and Human Physiological Fitness on Over-Ground Maneuver

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Thesis: Assessing the relationships of physiological, biomechanical, and mechanical parameters on wheelchair propulsion effort

Mechanical parameters

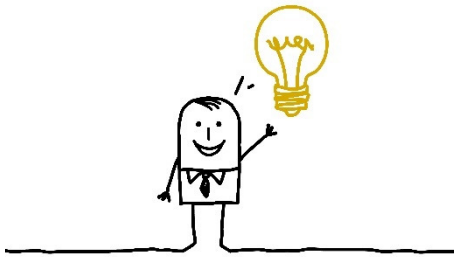
- Wheelchair mass [kg]
- System mass [kg]
- Rotational yaw inertia [kgm^2]
- **Weight distribution [%]**
- Frictional parameters (tile & carpet)
  - Deceleration-Straight (m/s^2)
  - Deceleration- Turn (m/s^2)
  - Fictional force (N)
  - Resistance torque (Nm)

Biomechanical parameters

- Shoulder position [cm]

Physiological parameters

- Propulsion strength (N/kg)
- **Predict VO_2 Max [ml/min·kg]**



Why study propulsion effort is important?

- Wheelchair propulsion is much less energy efficient than ambulation

-van der Woude et al. 1988

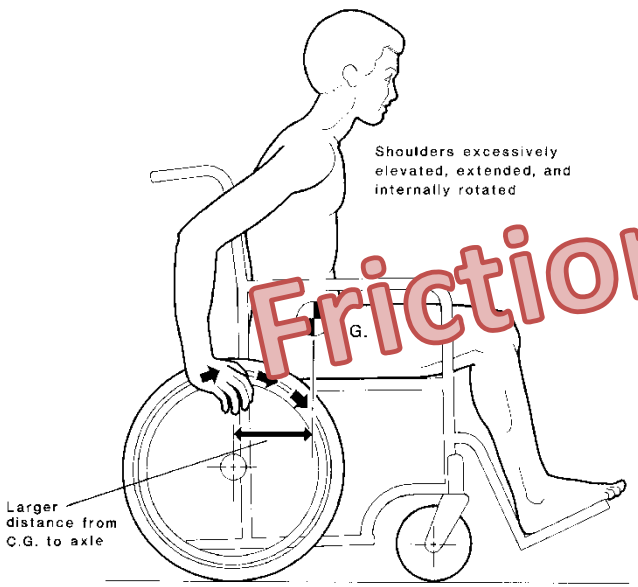
- Greater propulsion effort can lead to
  - difficulty in achieving desired speeds
  - a higher probability of fatigue over long bouts of mobility

-Boninger et al. 2003

  - difficulty negotiating inclines

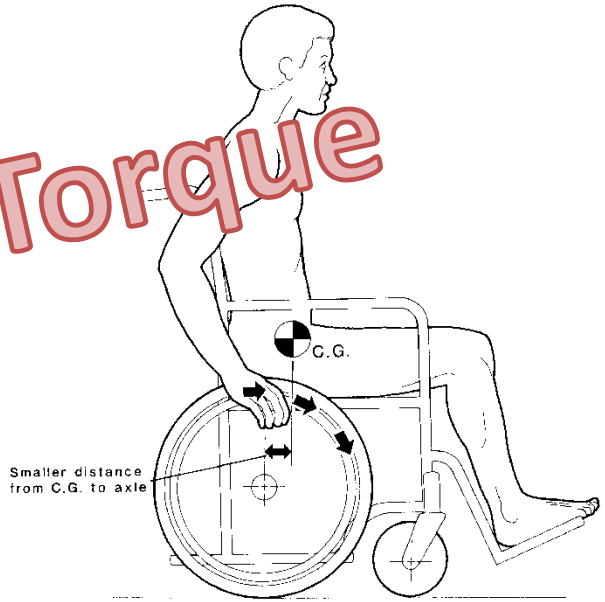
Why weight distribution?

K0001-rear axle position



55% weight on drive wheels

K0005-front axle position



70% weight on drive wheels

Friction & Torque

-Lin et al. 2015; Sprigle et al., 2015

Paper Objective

- Identify the relative influence of wheelchair ***weight distribution*** and ***human physiological fitness*** on the performance of free-wheeling activity.

Methods

- Subjects
  - Able-bodied: N=13
  - Full-time manual wheelchair users (MWUs): N=22
    - C-Level: 5; T-Level: 15; L-Level: 2
- *No significant difference* on physiological measurements between able-bodied and manual wheelchair user group

Example of propulsion metabolic effort [ml/kg·min] between two groups

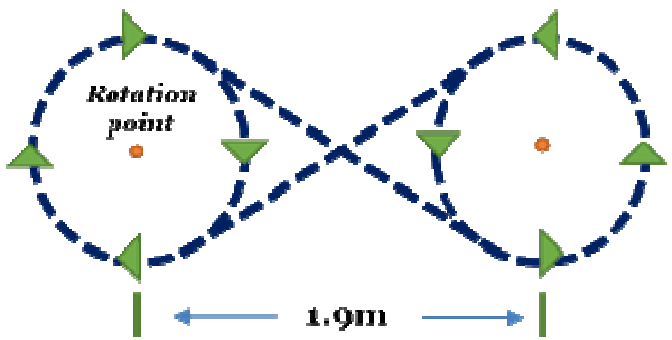
	Able-bodied	MWUs	Sig.	95% Confidence Interval difference	
Surface	Mean+S.E.	Mean+S.E.		Lower	Upper
Tile	7.4±0.5	7.2±0.4	0.752	-1.5	1.1
Carpet	10.6±2.0	9.5±2.4	0.207	-2.6	0.6

Protocol

- The first visit
  - Evaluate the mechanical properties of subjects' wheelchairs
    - Weight distribution and friction

-Eicholtz et al. 2015; Lin et al. 2015

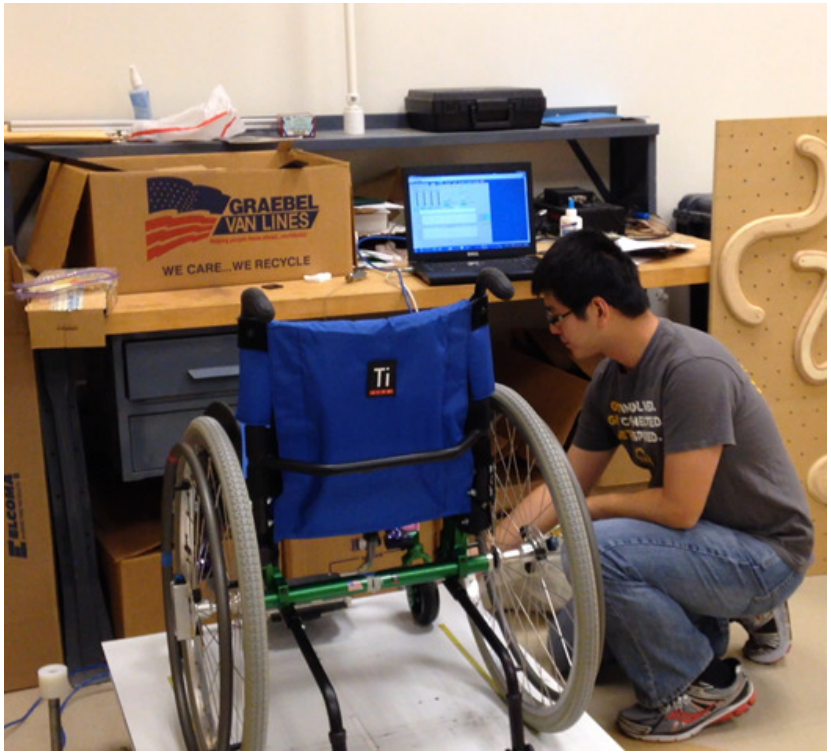
  - Evaluate the performance/effort of wheelchair propulsion
    - Over-ground maneuvers on both **tile** and **carpet** surfaces
- The second visit
  - Quantify subjects' physiological fitness
    - Predicted VO_2 Max



Mechanical measurements

Weight distribution

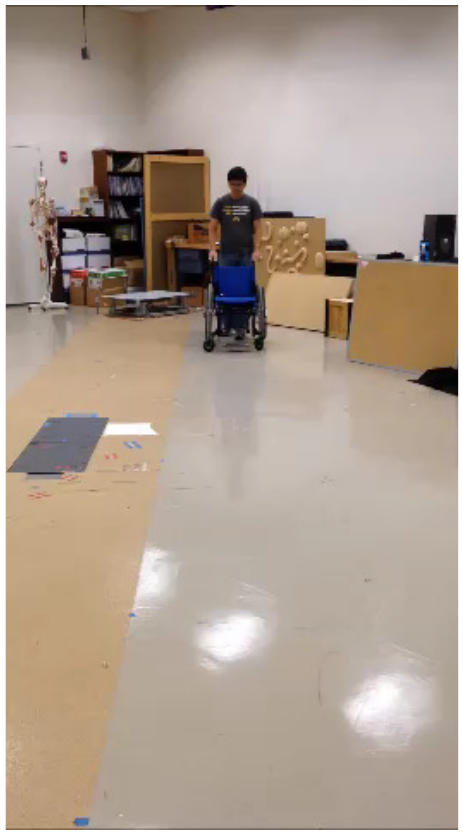
[% loading on drive wheels]



-Eicholtz et al. 2015

Overall friction

(Coast-down protocol)

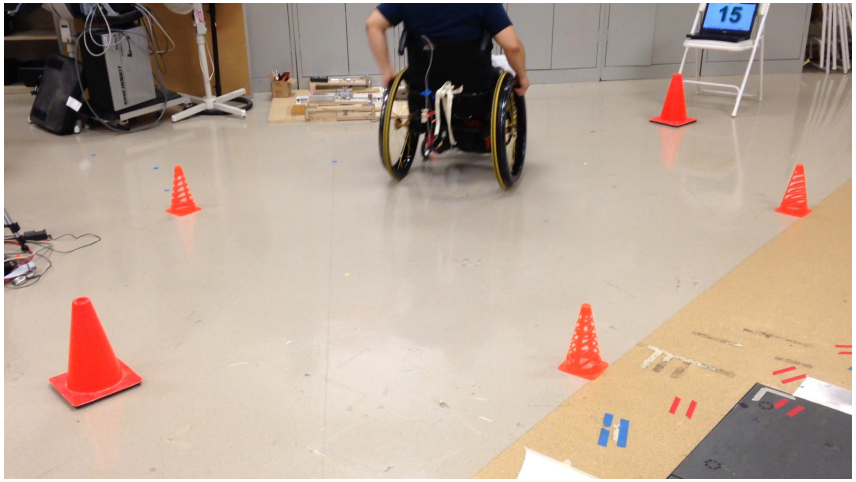


-Lin et al. 2015

Metabolic measurements

Propulsion demand [ml/min·kg]

- The last minute of net steady-state VO_2



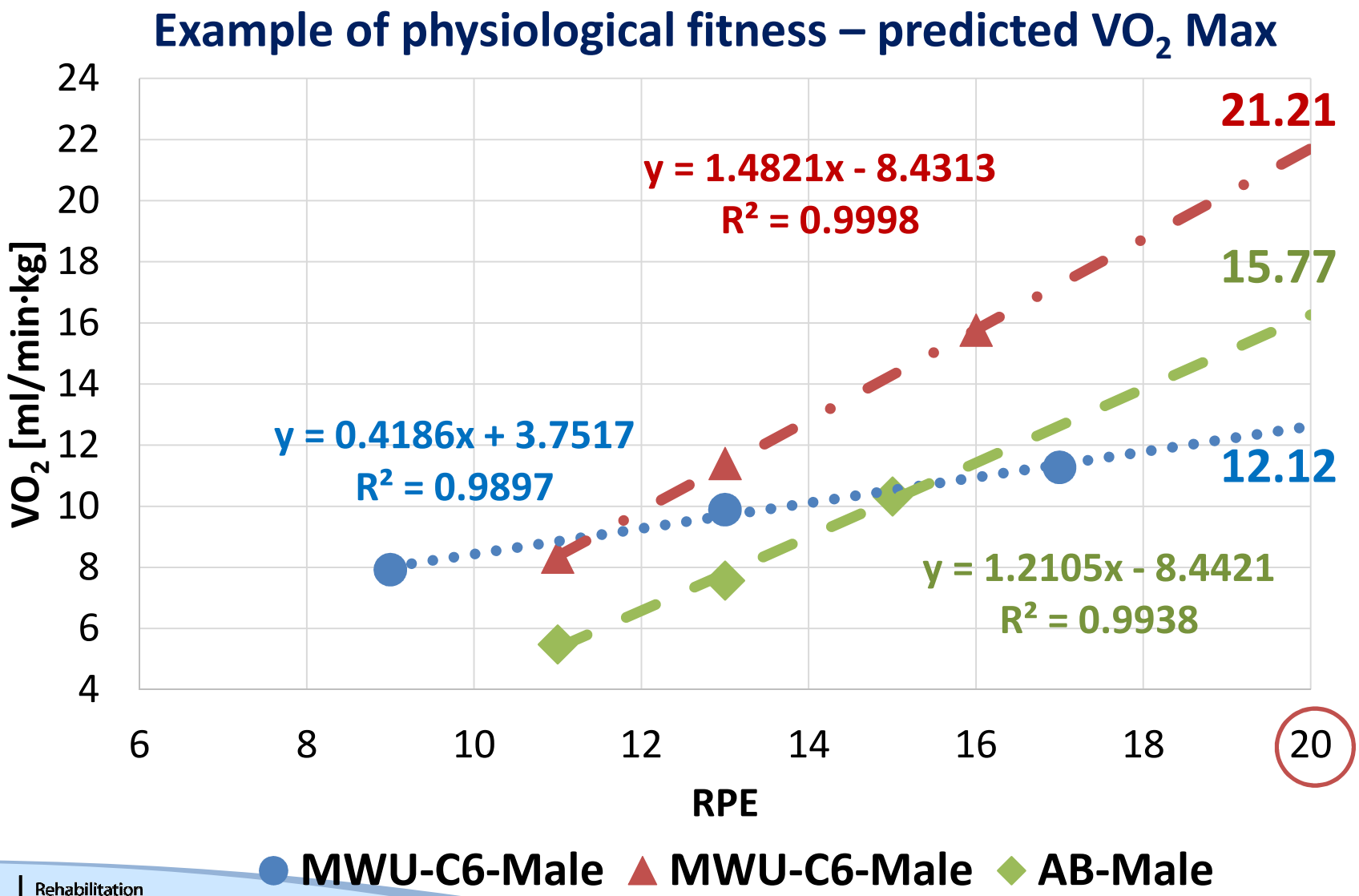
Physiological fitness [ml/min·kg]

- Predicted VO_2 Max from 3 stages of graded arm-cycling

-Goosey-Tolfrey, V.L., et al. 2014;

Al-Rahamneh, H.Q., et al.2011

Results

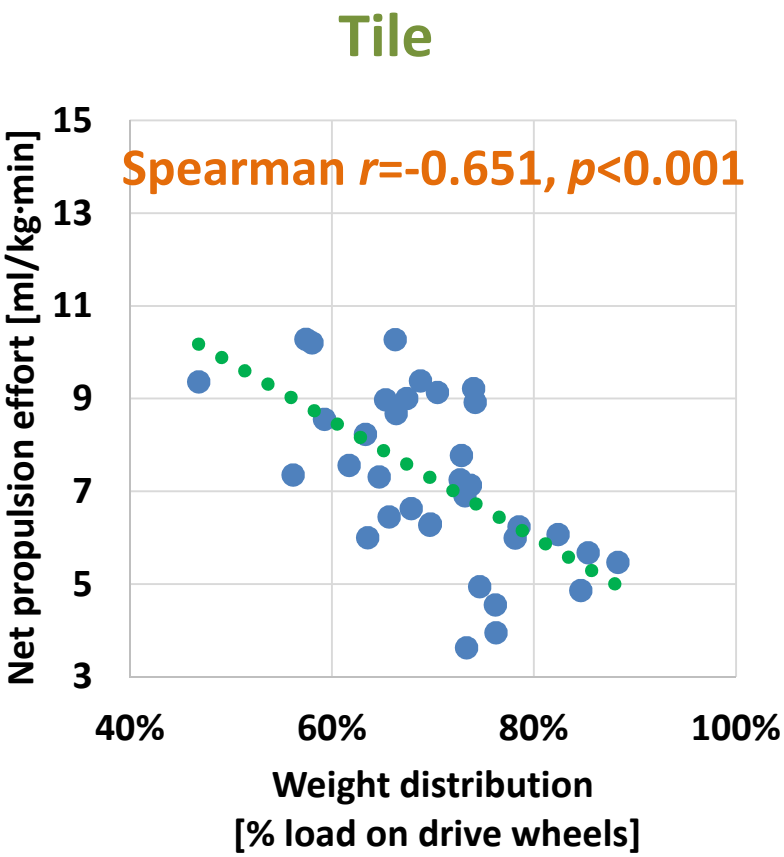

Example of physiological fitness – predicted VO2 Max
VO2 [ml/min·kg]
24
22
20
18
16
14
12
10
8
6
4
6
8
10
12
14
16
18
20
RPE
21.21
y = 1.4821x - 8.4313
R² = 0.9998
15.77
y = 0.4186x + 3.7517
R² = 0.9897
12.12
y = 1.2105x - 8.4421
R² = 0.9938
MWU-C6-Male
MWU-C6-Male
AB-Male

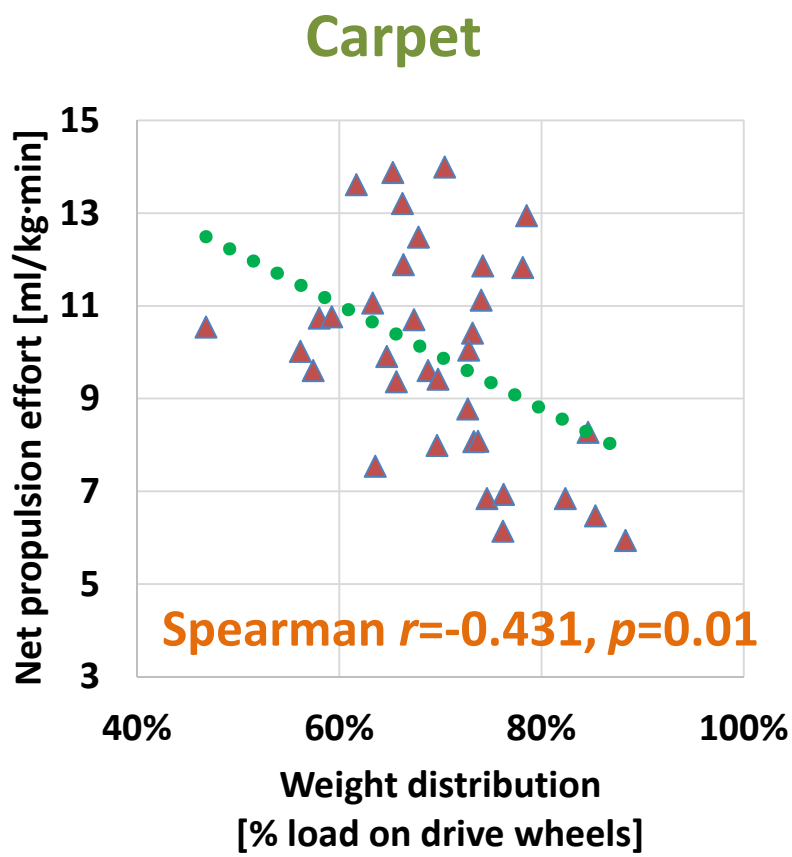
Regression model

Independent variables – Net propulsion effort on tile surface					
Coefficient	Unstandardized		Standardized		
	B	SE	Beta	Sig.	R^2
(constant)	16.34	1.98		0.000	0.37
Weight distribution (%)	-11.82	2.93	-0.57	0.000	
Physiological fitness (ml/min·kg)	-0.038	0.03	-0.15	0.265	

Independent variables – Net propulsion effort on carpet surface					
Coefficient	Unstandardized		Standardized		
	B	SE	Beta	Sig.	R^2
(constant)	17.85	2.92		0.000	0.14
Weight distribution (%)	-11.01	4.31	-0.42	0.016	
Physiological fitness (ml/min·kg)	-0.01	0.05	-0.04	0.0815	

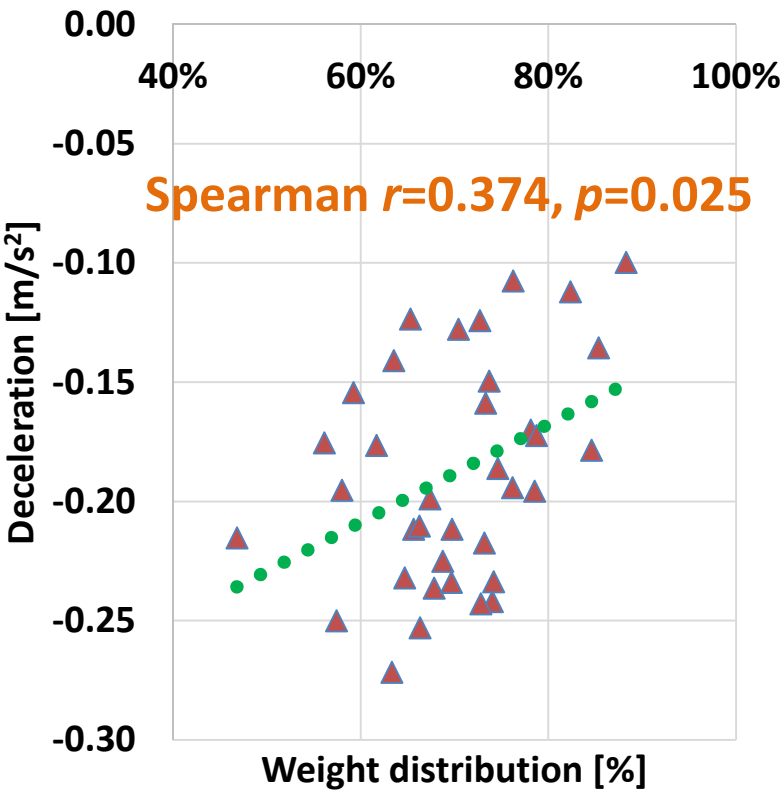
The relationship between propulsion effort and weight distribution



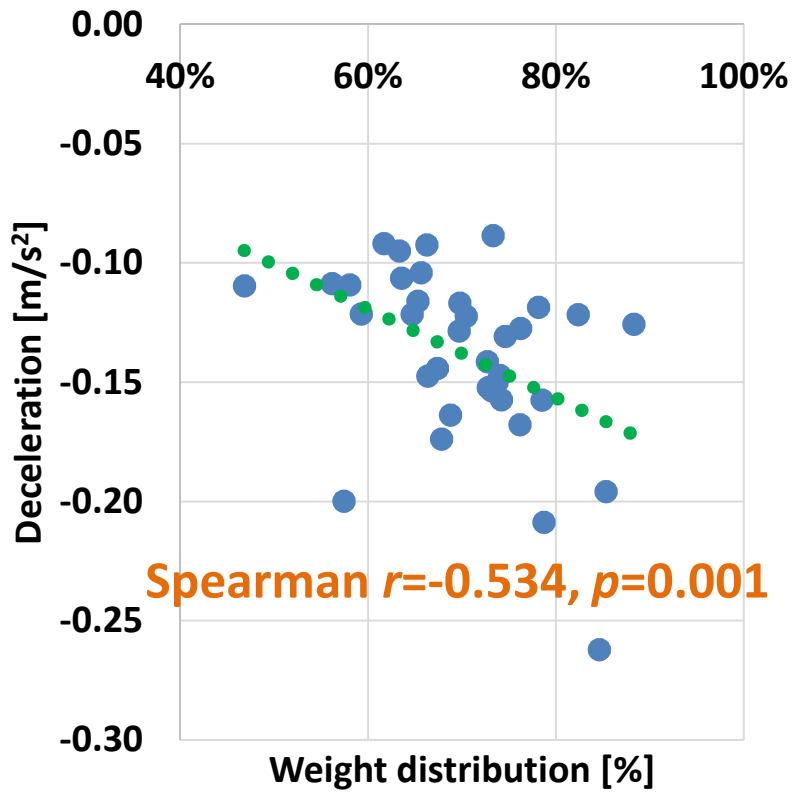


The impact of weight distribution on friction

Straight direction (Carpet)



Turns direction (Tile)



Discussion

- The **weight distribution** of the wheelchair system had a greater influence on propulsion effort than physiological fitness of the subject.
  - Subjects using wheelchairs with more loading on drive wheels tended to have lower propulsion effort.
  - Weight distribution is mainly affected by axle position
  - Increased loading on drive wheels would reduce propulsion torque on straight and turning motion.

-Sprigle et al., 2015

- Weight distribution influences the **overall energy loss** during **straight** and **turning** trajectories but <u>in a different manner</u>
  - Increase loading on the drive wheels increases friction during turning, but reduces friction in a straight trajectory.

-Lin et al. 2015

Summary

- The study provides a systematic approach to quantify the mechanical properties of the wheelchair system.
- This is the first time to study the related influence of wheelchair configuration and human physiological fitness on daily wheelchair propulsion.
- Wheelchair configuration, especially for weight distribution, has a greater influence than physiological fitness on over-ground maneuvers.

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