Kinematic State of the Hand at Impact with the Handrim as a Function of Handrim Compliance

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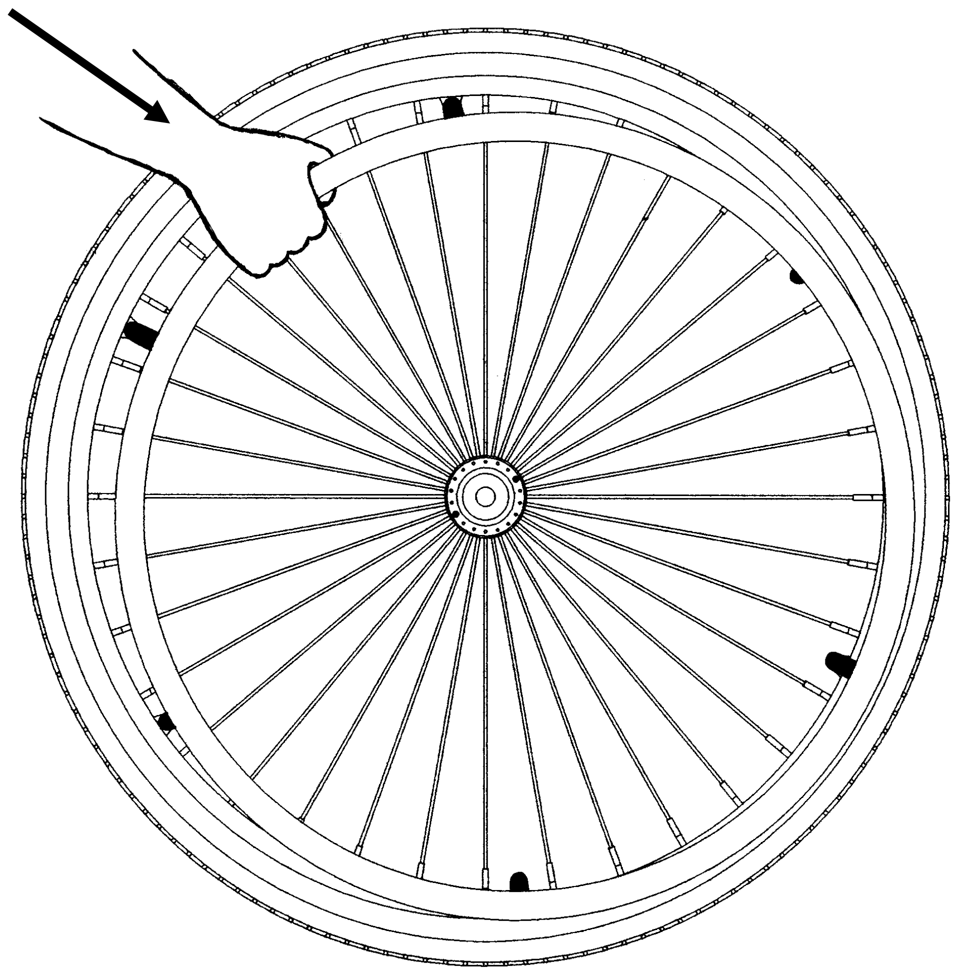
Motivation

- High incidence of upper extremity overuse injury
  - 64% of 239 wheelchair users (Sie, 1992)
- Association found between rate of rise of force on the handrim during propulsion and incidence of injury (Boninger, 1999)
  - “Impact phase” of propulsion

Compliant handrim

Designed to
reduce impact



Pilot compliant handrim research results

- Use of a compliant handrim found to reduce rate of rise of handrim force (Richter, 1999)
- Use of a compliant handrim found to reduce metabolic demand during propulsion (Richter, 1999)

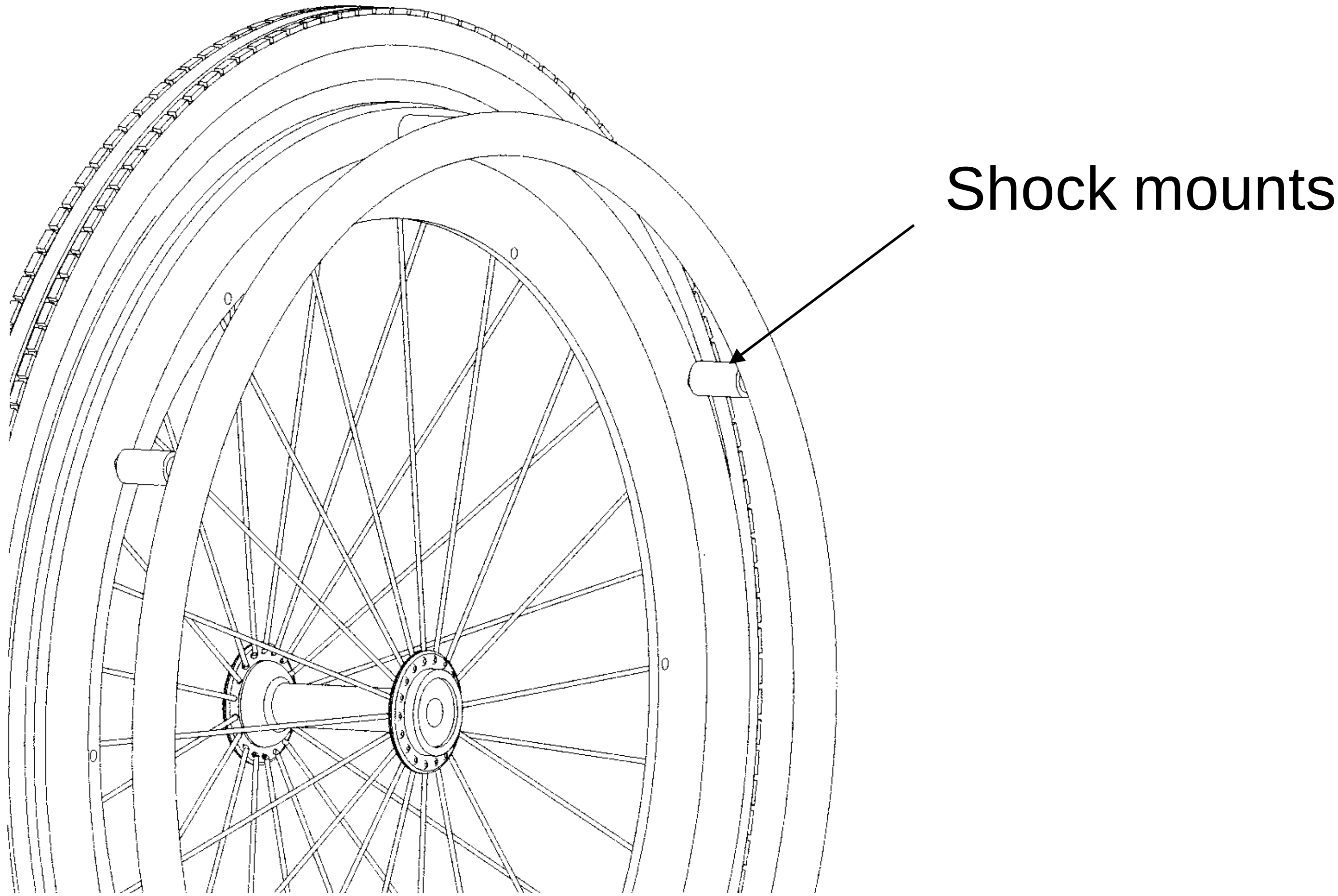
Unanswered questions

- Was the reduced rate of rise of force on the handrim due to the increased compliance or is the user adapting to the compliance by reducing the impact themselves?
- Was the reduced metabolic demand due to the increased compliance or is the user impacting the compliant handrim with more kinetic energy than the rigid handrim?

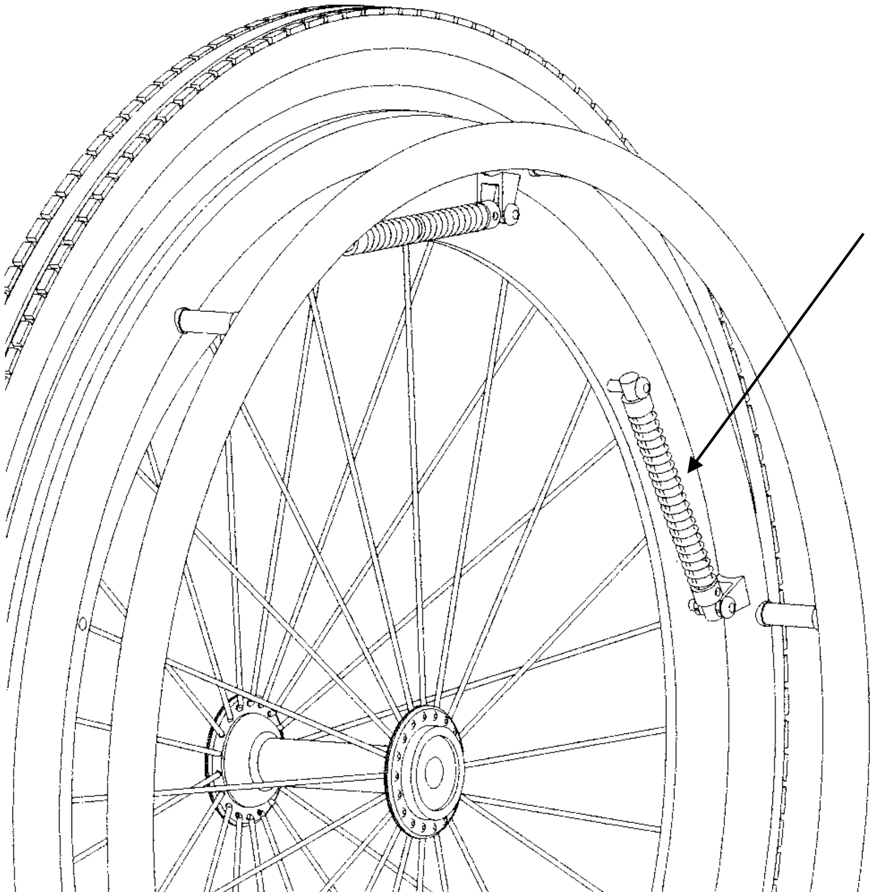
Specific aims

- Evaluate the velocity of the hand just prior to impacting the handrim during propulsion using a rigid handrim and compare that to the hand velocity when using a compliant handrim

Minimal compliance (Min)

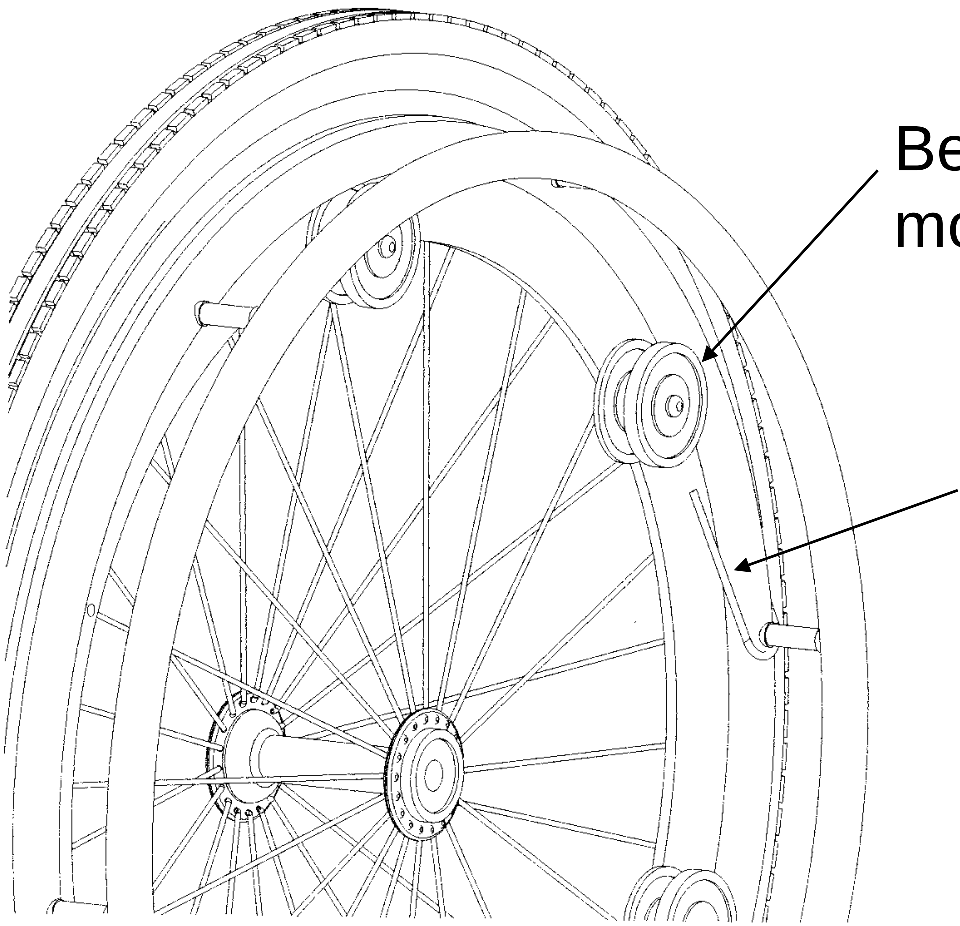


Maximal compliance (Max)



1 DOF, limited-travel
extension springs

Maximal compliance – rotation (Max-R)



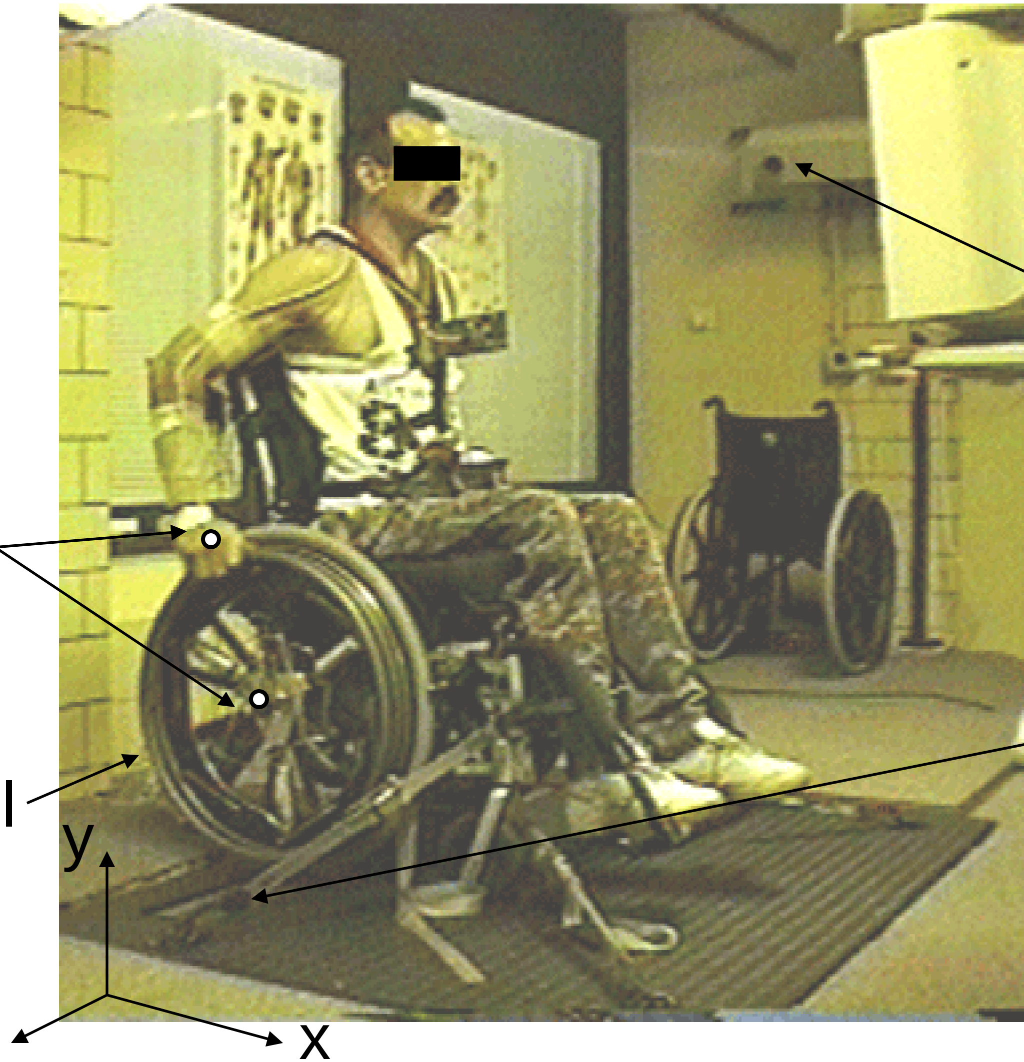
Bearing track constrains motion to rotation

Bungee cord provides elastic connection to wheel

Methodology

- 5 subjects propel wheelchair on a stationary dynamometer at target velocity (~2% grade)
- Propulsion kinetics measured using a SMARTWheel
- Propulsion kinematics measured using an Optotrak camera system with optical markers placed on relevant landmarks

Setup


Markers placed on 3rd MP joint and wheel hub
SmartWheel
OptoTrak (bilateral)
Dynamometer (independent left and right drums)
y
z
x

Methodology

- Kinetic and kinematic data collection triggered to ensure synchronous timing
- Data collected for 20 seconds, the first 10 pushes analyzed
- Data filtered using a 4^{th} order Butterworth type digital filter
  - Kinetic cutoff frequency = 20 Hz
  - Kinematic cutoff frequency = 7 Hz

Hand kinematics at impact

- $\mathbf{R}_{HH} = \mathbf{R}_{Hand} - \mathbf{R}_{Hub}$
  - $\mathbf{R}_{Hand}$ is the position vector of the hand
  - $\mathbf{R}_{Hub}$ is the position vector of the hub
  - $\mathbf{R}_{HH}$ is the position vector from the hub to the hand
- Impact is defined as point in time when force is first applied to the handrim
- $\theta_C = \mathrm{Cos}^{-1}(R_{HH}(y)/|\mathbf{R}_{HH}|)$
  - θ_C is the angle at which the hand first contacts the handrim

Hand kinematics at impact

- $\mathbf{V}_{Hand} = d\mathbf{R}_{Hand}/dt$
  - $\mathbf{V}_{Hand}$ is the velocity of the hand
  - 1/60th of a second before impact
- Hand velocity vector is transformed from a lab CS to a wheel-fixed CS
- $\mathbf{V}_{HW} = \mathbf{T}_{Contact} \bullet \mathbf{T}_{Camber} \bullet \mathbf{V}_{Hand}$
  - $\mathbf{V}_{HW}$ is the hand velocity w.r.t the wheel
  - $\mathbf{T}_{Contact}$ is a contact angle rotation matrix
  - $\mathbf{T}_{Camber}$ is a camber angle rotation matrix

Hand kinematics at impact

- Hand velocity components are radial, tangential, and lateral with respect to the wheel
- Handrim velocity is determined from angular velocity of the wheel and the diameter of the handrim
- Ratio of the tangential hand velocity to the handrim velocity is determined
- Results compared using a two-tailed paired samples t-test with significance set at $p=0.05$

Results

	Rigid	Min	Max	Max-R
Propulsion Speed (m/s)	1.28 (0.23)	1.30 (0.15)	1.22 (0.25)	1.29 (0.18)
Contact Angle (deg)	-21 (8)	-18 (7)	-21 (12)	-24 (7)

Results

	Rigid	Min	Max	Max-R
Hand Velocity (m/s)	0.90 (0.20)	0.84 (0.14)	0.88 (0.28)	0.89 (0.16)
Radial Hand Velocity (m/s)	0.34 (0.13)	0.32 (0.08)	0.38 (0.15)	0.33 (0.10)
Tan Hand Velocity (m/s)	0.80 (0.23)	0.78 (0.20)	0.76 (0.32)	0.80 (0.20)
Lateral Hand Velocity (m/s)	0.00 (0.09)	0.00 (0.06)	0.02 (0.10)	0.02 (0.08)

Results

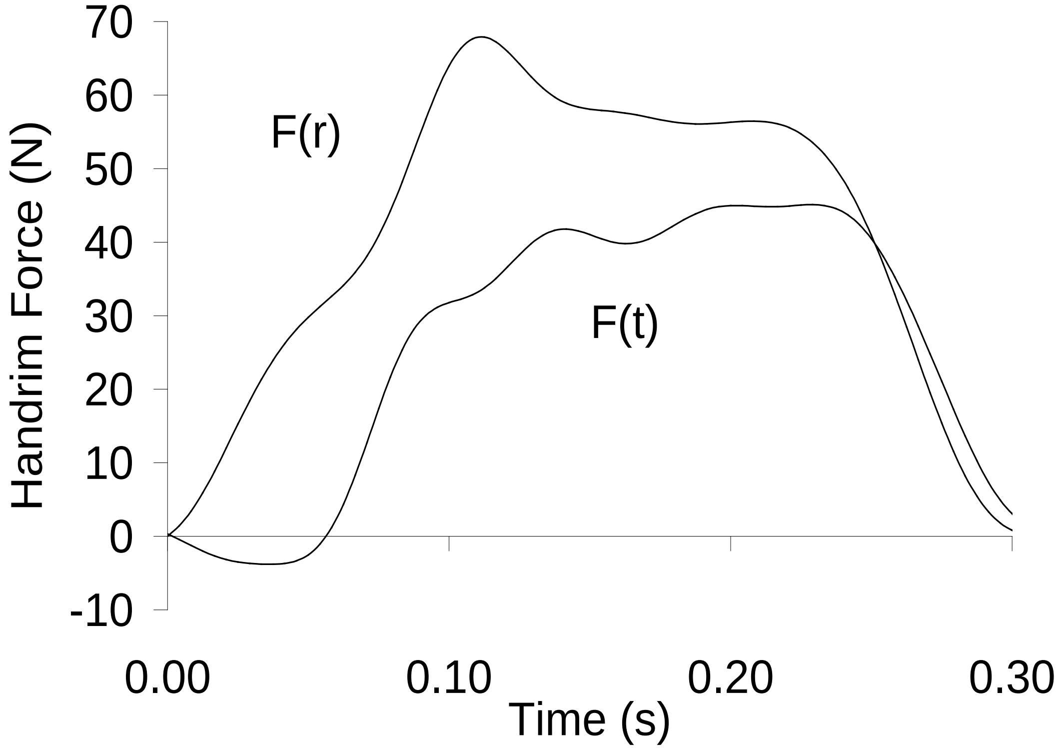
	Rigid	Min	Max	Max-R
(Tangential Hand Velocity) / (Handrim Velocity)	0.72 (0.06)	0.67 (0.15)	0.70 (0.15)	0.73 (0.08)

* Tangential hand velocity lags the pushrim

Discussion

- Hand velocity is not affected by handrim compliance
  - Reduced impact and metabolic demand found in pilot study are likely due to changes in compliance and not changes in kinematics
- Most notable results from study are the magnitude of the hand velocity components
  - Hand is being driven into the handrim radially, a direction the handrim does not generally move
  - Hand speed lags the handrim speed in the tangential direction
  - Lateral hand velocity is essentially zero

Handrim force profile



- Radial force has an impact spike
- Tangential force has an initially negative component
- Force profile similar to that found by Boninger et al. (1997)

Looking ahead

- It is possible that hand velocity at impact varies among wheelchair users and various propulsion styles
- It is possible that users with a higher radial hand velocity component or a low tangential velocity ratio may have a higher risk of developing over use injuries
- It is recommended that future studies incorporate hand velocity among those metrics already being assessed

Limitations

- Study was performed using a small number of users
- Adaptation time to compliant handrims was limited

Acknowledgements

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References

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Questions