Handcycling: a biophysical analysis

PhD thesis of Ursina Arnet

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18. 10. 2013
Background of the study

Problem: high prevalence of shoulder pain:
• persons with SCI: 30 - 73% (Ballinger 2000)
• general population: 7 - 27% (Luime 2004)

Most common cause of shoulder pain: overuse injuries to the rotator cuff, impingement syndrome
Overuse injuries to the shoulder

- anatomy
- nutrition
- too much/wrong load
- not optimal movement pattern
- training status
- ...

Overuse injuries
Shoulder load and SCI

Possible etiology:

• Repetitive forces acting on the shoulder joint (Kulig 1998)

• High peak forces applied to the push rim (Boninger 2003) and high moments acting on the shoulder joint (Mercer 2006)
Shoulder load and SCI

Lower the shoulder load
• power wheelchair
• optimization, adjustment of wheelchair
• training
• different propulsion mechanism: lever propulsion, handcycling

Aim of the thesis:
To analyze the physical strain and efficiency of handcycling and its accompanying mechanical load on the shoulder complex.
Thesis

Main aspects:
1. handcycling: testing and measuring
2. handbike vs. handrim wheelchair propulsion
3. the optimal setup of the handbike
1. Handcycling

Aim: to get a baseline knowledge of handbike propulsion and its reaction to different test situations.
1. Handcycling

- Validation study: background on technical details and accuracy of measured forces.\(^1\)

- Influence of exercise condition on the applied forces: effect of speed and method to impose power output; \(\rightarrow\) effect of speed, no effect of method to impose power.

- Handcycling styles at different power output levels; \(\rightarrow\) different styles at different power output levels, not possible to identify most efficient style.

\(^2\) Arnet et al. Are the force characteristics of synchronous handcycling affected by speed and method to impose power? Med Eng Phys 2012: 78-84
\(^3\) Arnet et al. Propulsion style and mechanical efficiency during handcycling at different power outputs. Submitted to the Journal of Sports Sciences
2. Handbike vs. Wheelchair

Aim: to identify if the handbike is a good alternative mobility device with respect to shoulder load.

Quantification of shoulder load:
• applied hand forces
• shoulder moments
• glenohumeral contact forces
• muscle forces
Hand forces

Total applied hand force

Wheelchair          Handbike
Hand forces

Total applied hand force

Wheelchair: 4% incline, 51 W

Handbike: lower peak and mean forces → indication for lower shoulder load

4 Arnet et al. Force application in handcycling and handrim wheelchair propulsion: an initial comparison. Submitted to Journal of Applied Biomechanics
2. Handbike vs. Wheelchair

Quantification of shoulder load:

• applied hand forces: HB < WC
• shoulder moments
• glenohumeral contact forces
• muscle forces
Shoulder moments

Moment = force x lever arm
Shoulder moments

Wheelchair: 4% incline, 51 W

Handbike: lower peak and mean moments

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2. Handbike vs. Wheelchair

Quantification of shoulder load:

- applied hand forces: $\text{HB} < \text{WC}$
- shoulder moments: $\text{HB} < \text{WC}$
- glenohumeral contact forces
- muscle forces
Glenohumeral contact force = sum of external and internal forces

Delft Shoulder and Elbow Model
Musculoskeletal model

Delft Shoulder and Elbow model:
31 muscles, bones, ligaments

• Inverse dynamic
  minimum stress/energy cost function
  maximal force per physiological cross section = 100N/cm²

• Input: External forces applied by hand
  Orientation of thorax, clavicle, scapula, humerus, forearm, hand
Musculoskeletal model

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• Input: External forces applied by hand
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• Output: GH joint reaction force
  relative muscle forces
Glenohumeral contact force

Wheelchair: 55W

Handbike: lower peak and mean forces

2. Handbike vs. Wheelchair

Quantification of shoulder load:

• applied hand forces: HB < WC
• shoulder moments:   HB < WC
• glenohumeral contact forces : HB < WC
• muscle forces
Muscle forces

Rotator cuff: supraspinatus, infraspinatus, subscapularis, teres minor

† stabilization of shoulder joint
Muscle forces

Wheelchair: 55W

Handbike: lower peak and mean muscle forces, mainly on rotator cuff

2. Handbike vs. Wheelchair

Quantification of shoulder load:

• applied hand forces: HB < WC
• shoulder moments: HB < WC
• glenohumeral contact forces: HB < WC
• muscle forces: HB < WC

→ The handbike is favorable to the handrim wheelchair for outdoor mobility and exercise and it has the potential to reduce overuse injuries to the shoulder.
3. Handbike Setup

aim:

• Performance → high efficiency, low air resistance
• Recreation, health maintenance → low shoulder load
3. Handbike Setup

Aim: to identify the setup of the handbike where the shoulder load is the lowest.

Analyzed variables:
- backrest inclination
- crank position (height and distance)
## Protocol

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<thead>
<tr>
<th>Crank position</th>
<th>Trial name</th>
<th>backrest inclination</th>
<th>crank distance (elbow angle)</th>
<th>crank height</th>
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<tbody>
<tr>
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<td>close, high</td>
<td>60°</td>
<td>35°</td>
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![Diagram of bike setup](image-url)
Measured outcome

- glenohumeral contact forces
- muscle forces
- mechanical efficiency (ME):
  \[
  ME = \left( \frac{\text{power output}}{\text{energy consumption}^*} \right) \cdot 100% 
  \]

* calculated with \( O_2 \) consumption and respiratory exchange ratio
Backrest inclination

Glenohumeral contact force

* = significant differences between setups
Backrest inclination

Muscle forces

* = significant differences between setups
Backrest inclination

Mechanical efficiency

upright backrest position: less shoulder load $^6$

$\rightarrow$ air resistance

Crank position

Glenohumeral contact force

* = significant differences between setups
Crank position

Muscle forces

* = significant differences between setups
Crank position

Mechanical efficiency

* = significant differences between setups

mean values
peak values

Distant crank position: less load on the subscapularis

Optimal position

- Upright backrest (inclination = 60°)
- Distant crank position (elbow angle = 15°)
Conclusion

All in all the handbike is preferred for outdoor mobility over the manual handrim wheelchair. With an optimal adjustment to its user, the increased use of the handbike can prevent overuse injuries and improve the physical fitness and mobility of wheelchair dependent persons.
Thanks for the attention!

Questions?
Point of contact of the glenohumeral contact force

Wheelchair

Handbike