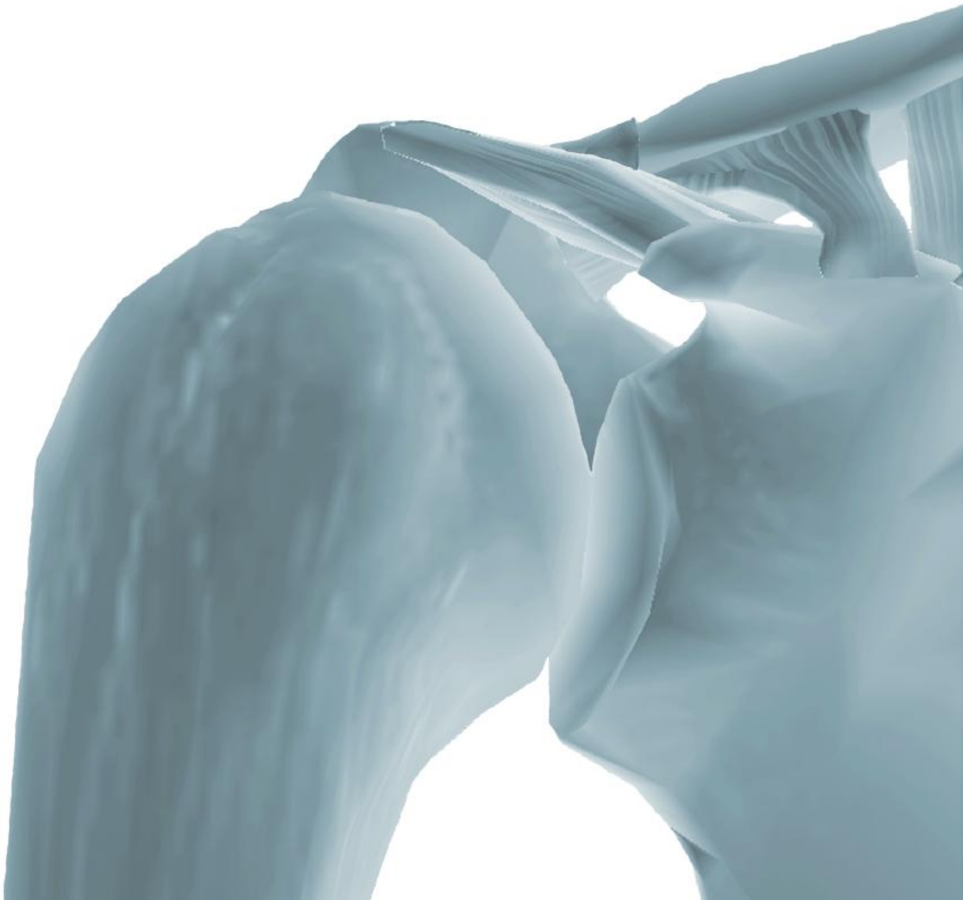
Handcycling:
a biophysical analysis

PhD thesis of
Ursina Arnet

Mini-Symposium, Utrecht
18. 10. 2013

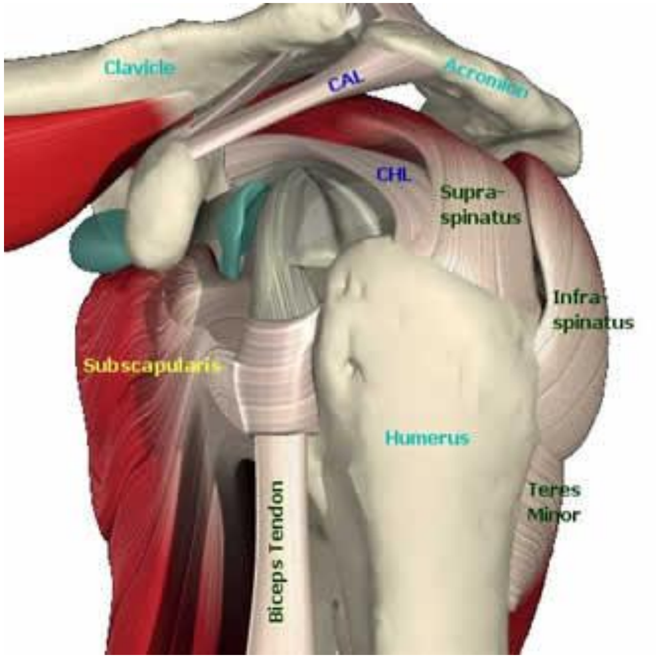


Background of the study

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

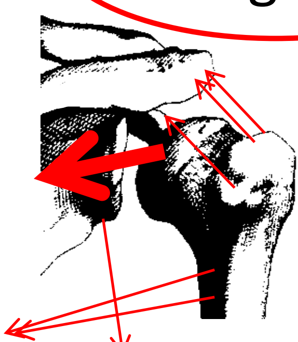
nutrition

anatomy

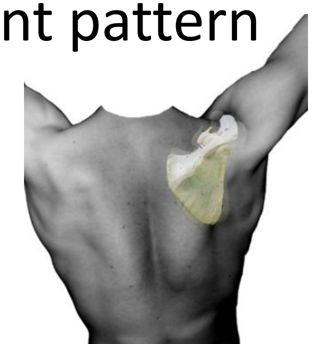
training status

Overuse injuries

too much/ wrong load



not optimal movement pattern



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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 stra[illegible]ency of handcycling and its accompanying mechani[illegible]e shoulder complex.

Thesis

Main aspects:

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

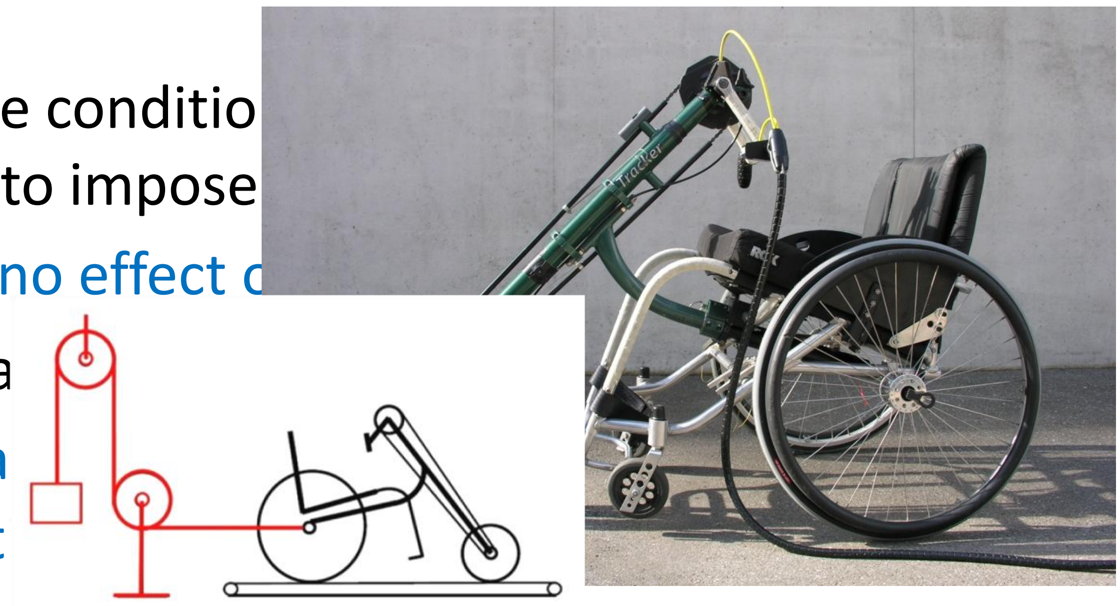
1. Handcycling

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 conditio speed and method to impose
  → effect of speed, no effect o



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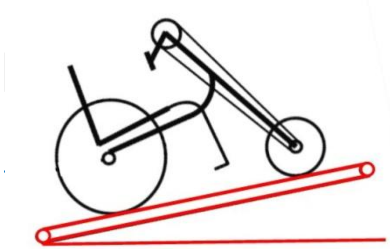


[1] van Drongelen et al. Development and validity of an instrumented handbike: initial results of propulsion kinetics. Med Eng Phys 2011: 1167-1173
[2] Arnet et al. Are the force characteristics of synchronous handcycling affected by speed and method to impose power? Med Eng Phys 2012: 78-84
[3] Arnet et al. Propulsion style and mechanical efficiency during handcycling at different power outputs. Submitted to the Journal of Sports Sciences

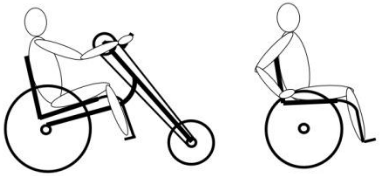
2. Handbike vs. Wheelchair  

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

Quantification of shoulder load:

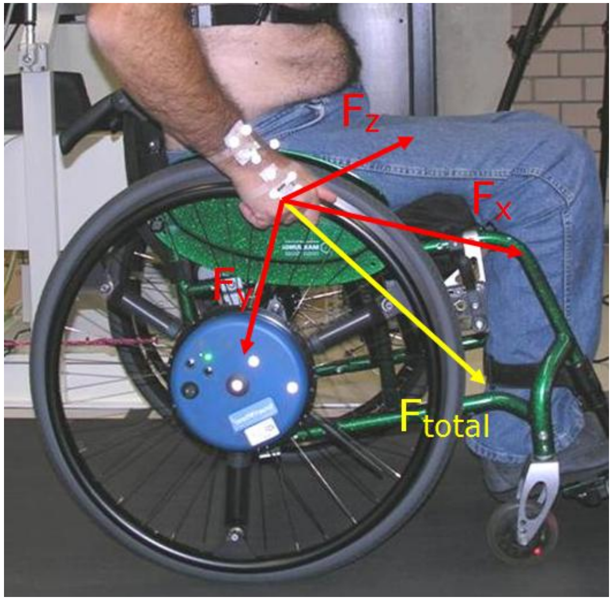
- applied hand forces
- shoulder moments
- glenohumeral contact forces
- muscle forces

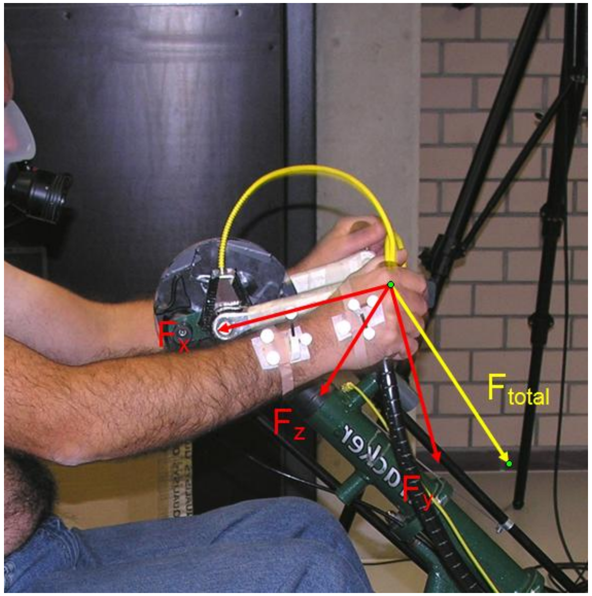
Hand forces



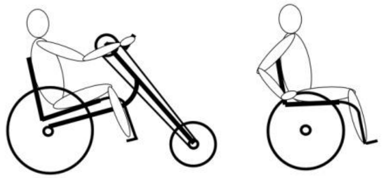
Total applied hand force

Wheelchair Handbike



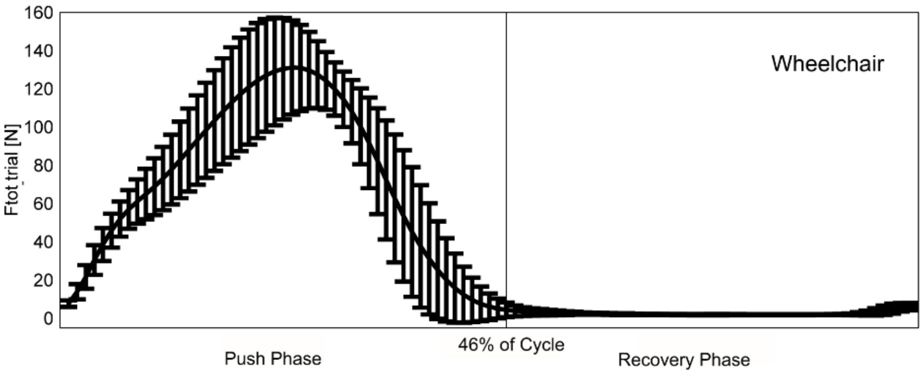


Hand forces



Total applied hand force

Wheelchair: 4% incline, 51 W

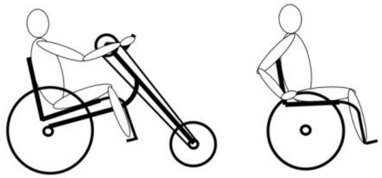


Handbike: lower peak and mean forces [4]

→ 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:

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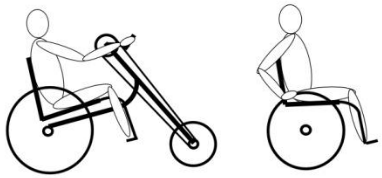
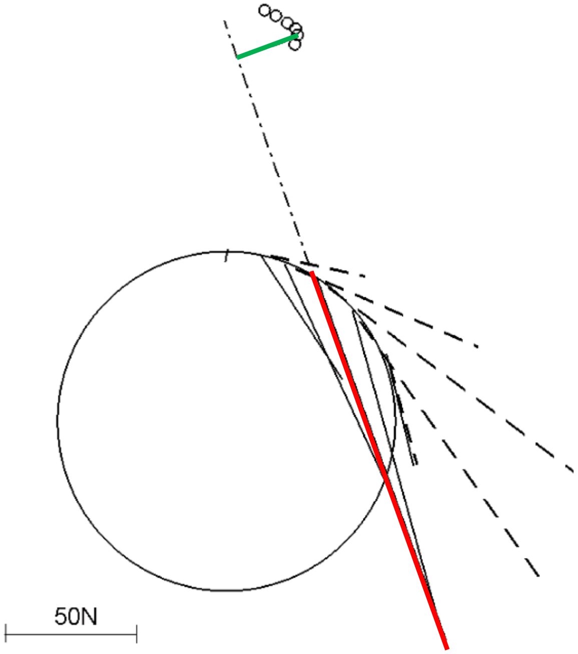
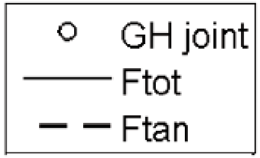
Shoulder moments



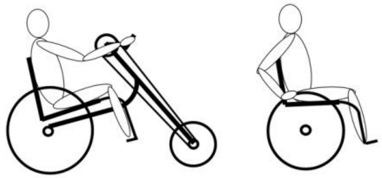
Moment = force x lever arm

Wheelchair Handbike





Shoulder moments



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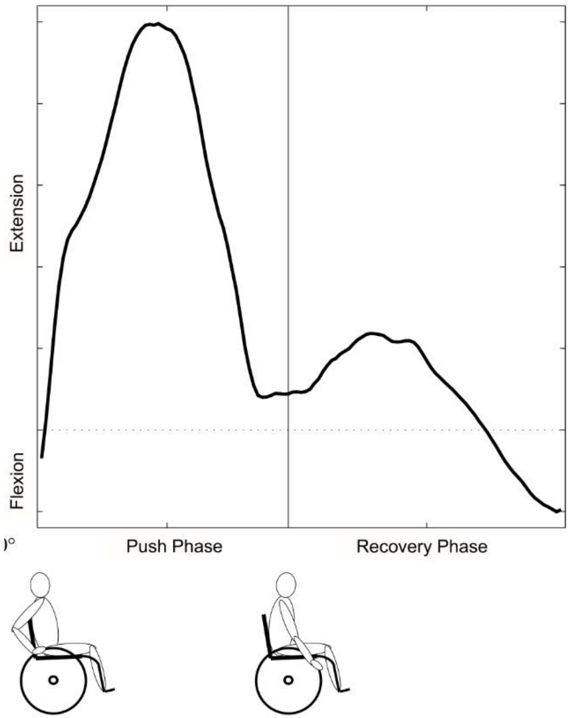

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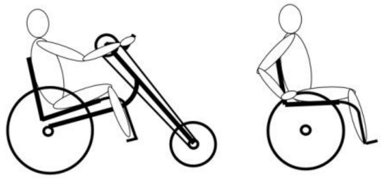
2. Handbike vs. Wheelchair



Quantification of shoulder load:

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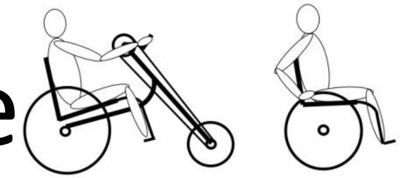
- shoulder moments: HB < WC
- glenohumeral contact forces
- muscle forces

Glenohumeral contact force

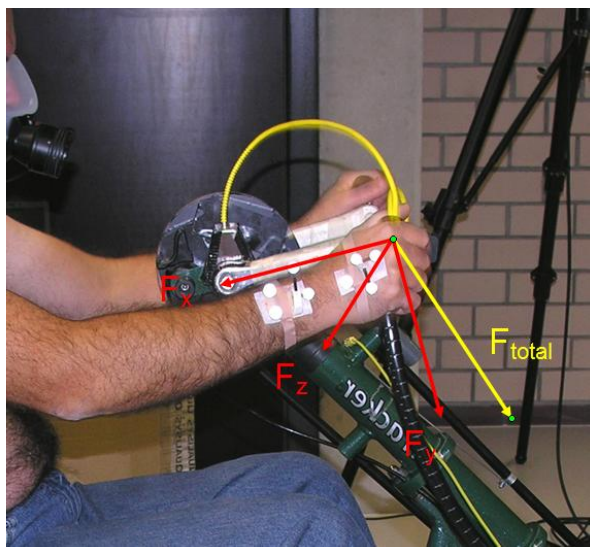


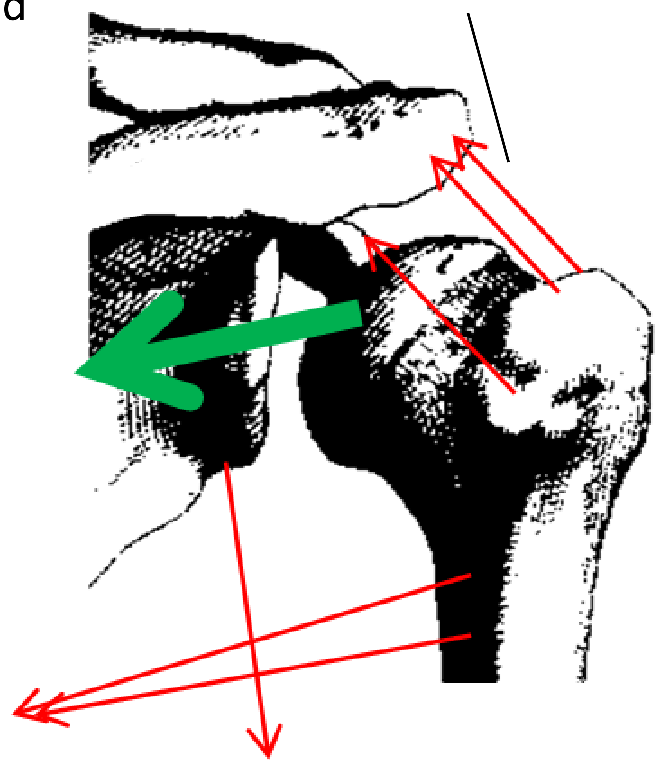
Glenohumeral contact force = sum of external and internal forces

↳ Delft Shoulder and Elbow Model

measured

calculated





Musculoskeletal model

Delft Shoulder and Elbow model:

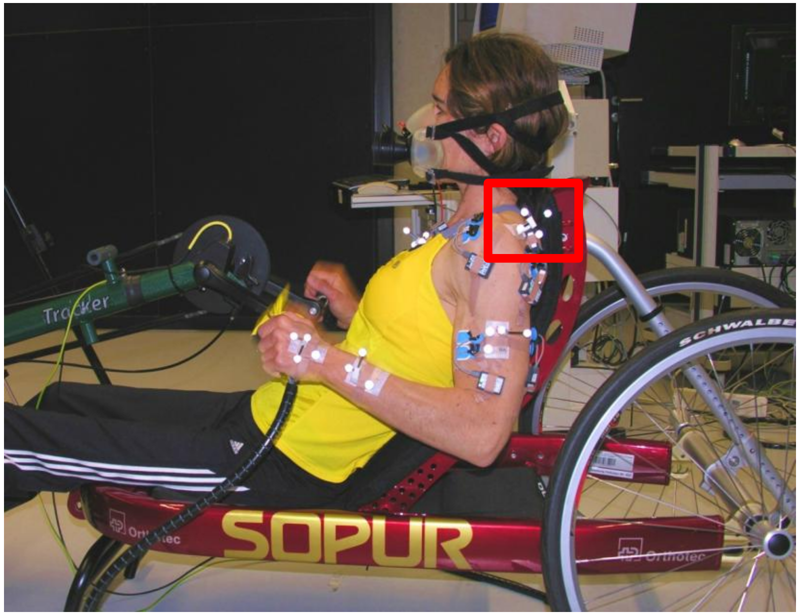
31 muscles, bones, ligaments

•Inverse dynamic

minimum stress/energy cost function

maximal force per physiological

cross section = 100N/cm^2



•Input: External forces applied by hand

Orientation of thorax, clavicle,

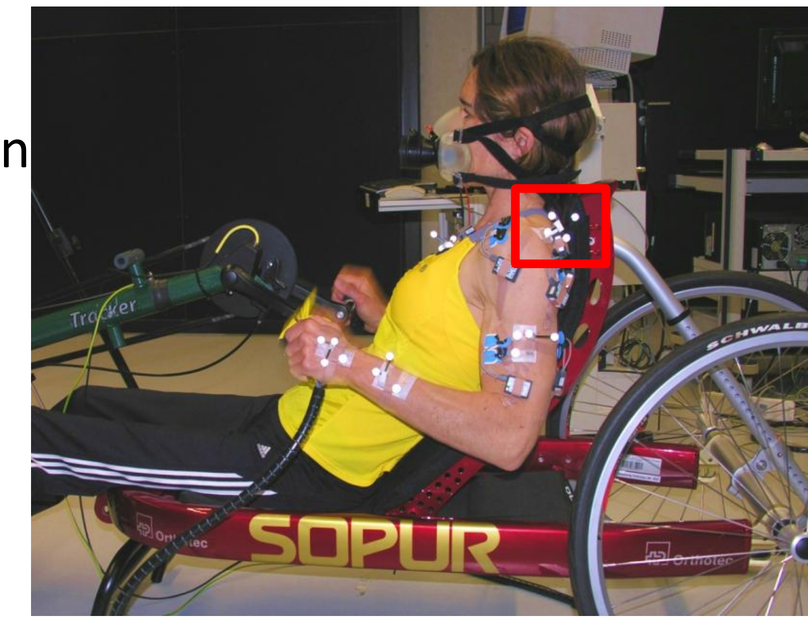
scapula, humerus, forearm, hand

Musculoskeletal model

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

Kinematics: Orientation of thorax, clavicle, scapula, humerus, forearm, hand

- Inverse dynamic
    - minimum stress/energy cost function
    - maximal force per physiological
        - cross section = $100 N/cm^2$



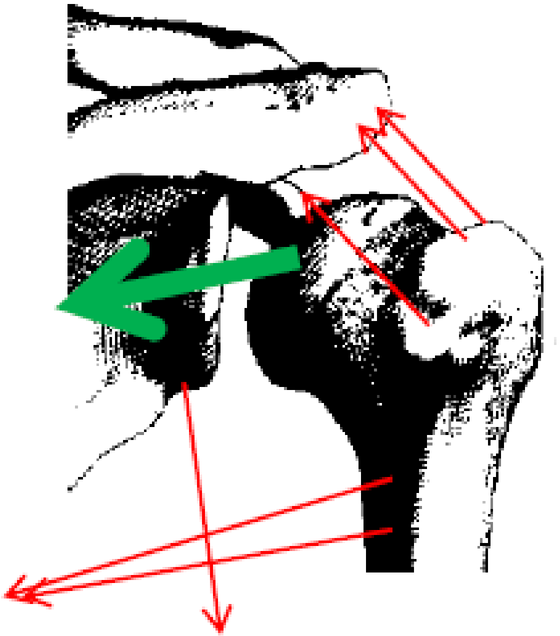
- Input: External forces applied by hand
    - Orientation of thorax, clavicle,
    - scapula, humerus, forearm, hand

Musculoskeletal model

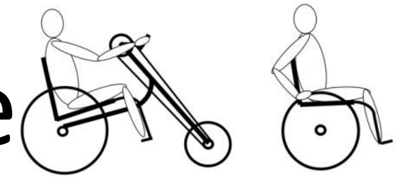
Delft Shoulder and Elbow model:

31 muscles, bones, ligaments

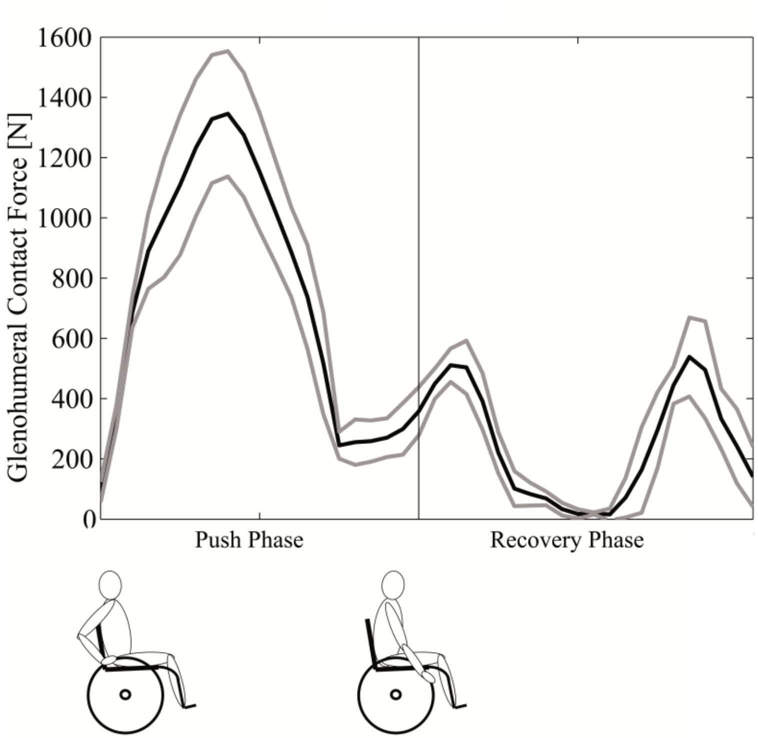
- Inverse dynamic
  - minimum stress/energy cost function
  - maximal force per physiological
    - cross section = 100N/cm^2
- Input: External forces applied by hand
  - Orientation of thorax, clavicle,
  - scapula, humerus, forearm, hand
- Output: GH joint reaction force
  - relative muscle forces



Glenohumeral contact force



Wheelchair: 55W



Handbike: lower peak and mean forces [5]

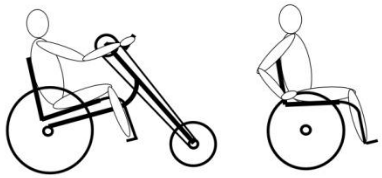
[5] Arnet et al. Shoulder load during synchronous handcycling and hand rim wheelchair propulsion in persons with paraplegia. Journal of Rehabilitation Medicine 2012: 222-228.

2. Handbike vs. Wheelchair  

Quantification of shoulder load:

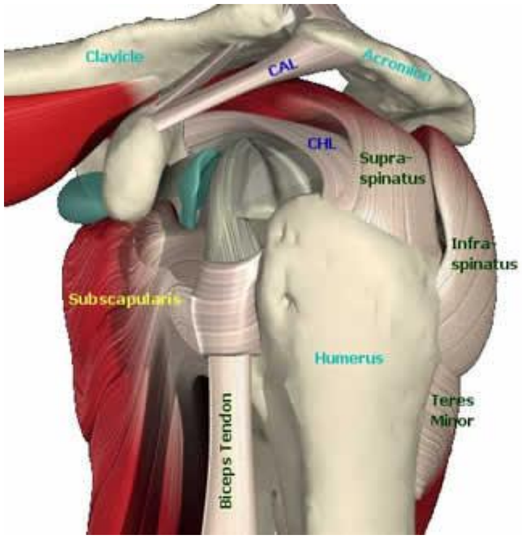
- applied hand forces: HB < WC
- shoulder moments: HB < WC
- glenohumeral contact forces : HB < WC
- muscle forces

Muscle forces

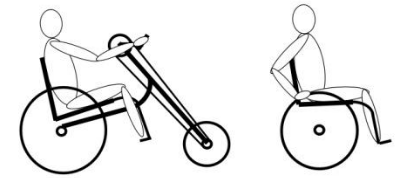


Rotator cuff: supraspinatus, infraspinatus, subscapularis, teres minor

↳ stabilization of shoulder joint



Muscle forces



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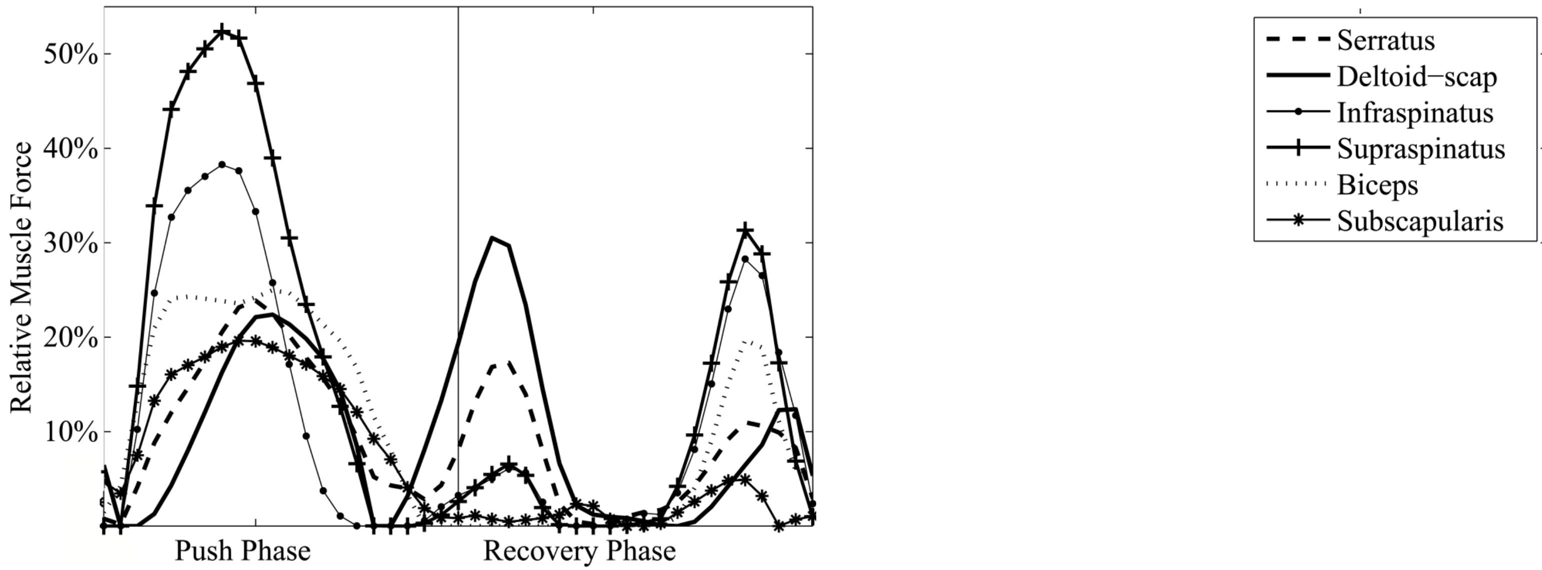
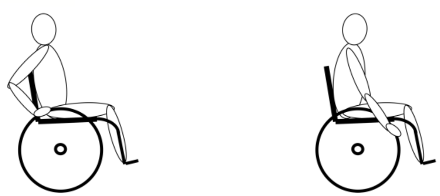




Handbike: lower peak and mean muscle forces, mainly on rotator cuff [5]

[5] Arnet et al. Shoulder load during synchronous handcycling and hand rim wheelchair propulsion in persons with paraplegia. Journal of Rehabilitation Medicine 2012: 222-228.

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.

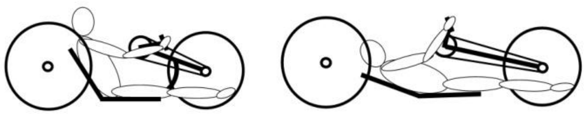
3. Handbike Setup

optimal position?

aim:

- Performance → high efficiency, low air resistance
- Recreation, health maintenance → low shoulder load

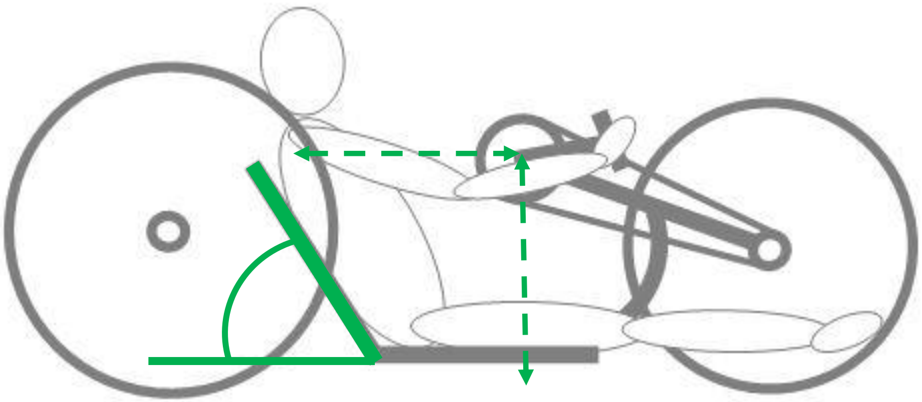
3. Handbike Setup



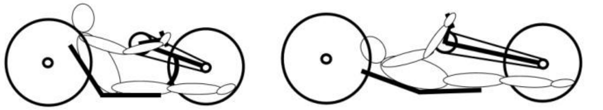
Aim: to identify the setup of the handbike where the shoulder load is the lowest.

Analyzed variables:

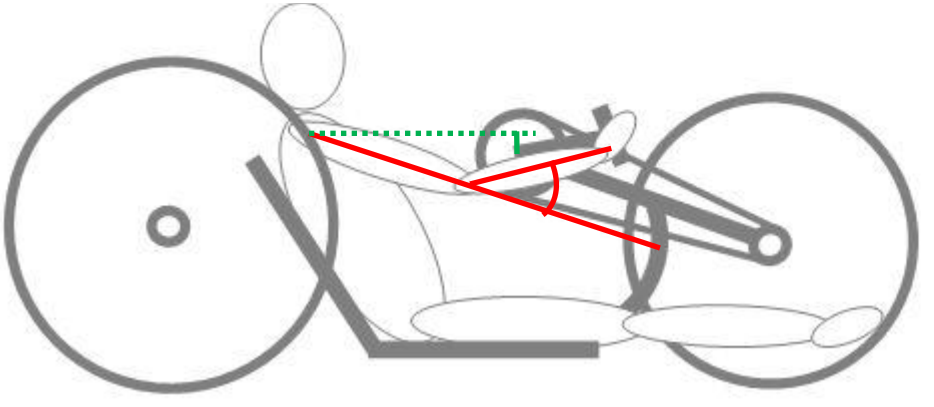
- backrest inclination
- crank position
  (height and distance)



Protocol



		Trial name	backrest inclination	crank distance (elbow angle)	crank height
Crank	position	close, high	60°	35°	shoulder height
		close, low	60°	35°	shoulder height -15% arm length
		distant, high	60°	15°	shoulder height
		distant, low	60°	15°	shoulder height -15% arm length
Backrest	inclination	60°	60°	15°	shoulder height -15% arm length
		45°	45°	15°	shoulder height -15% arm length
		30°	30°	15°	shoulder height
		15°	15°	15°	shoulder height +15% arm length



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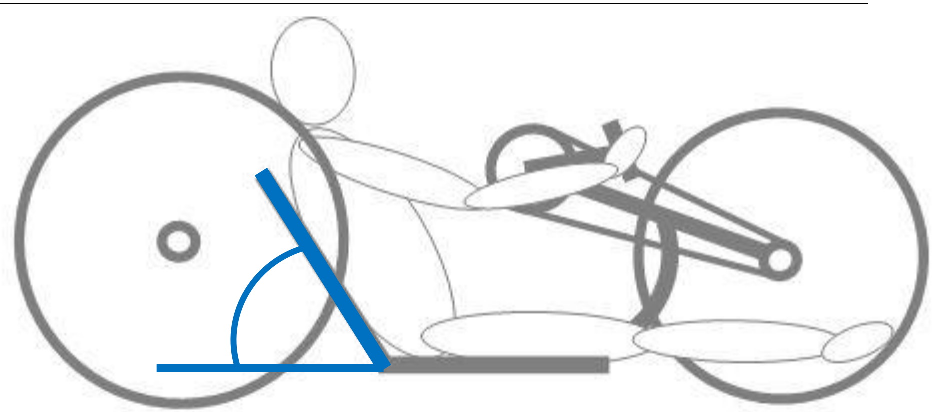
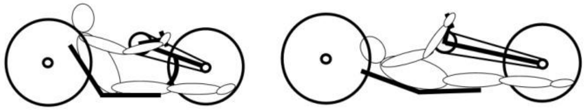
Backrest inclination	60°	60°	15°	shoulder height -15% arm length
	45°	45°	15°	shoulder height -15% arm length
	30°	30°	15°	shoulder height
	15°	15°	15°	shoulder height +15% arm length



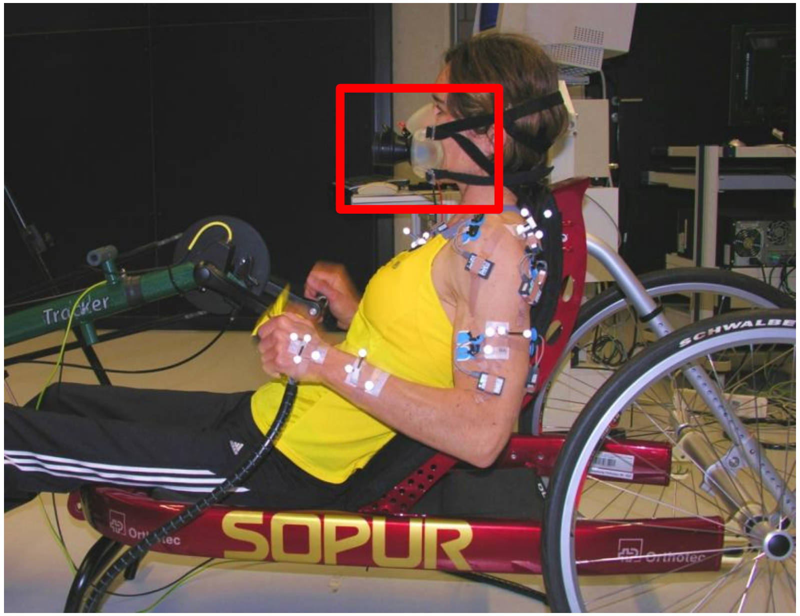
Measured outcome



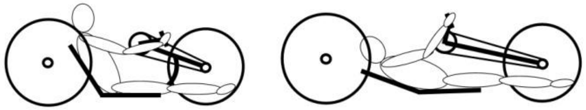
- glenohumeral contact forces
- muscle forces
- mechanical efficiency (ME):

  ME = (power output / energy consumption*) ·100%

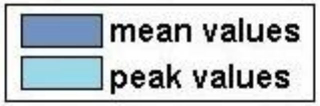
* calculated with O_2 consumption and respiratory exchange ratio

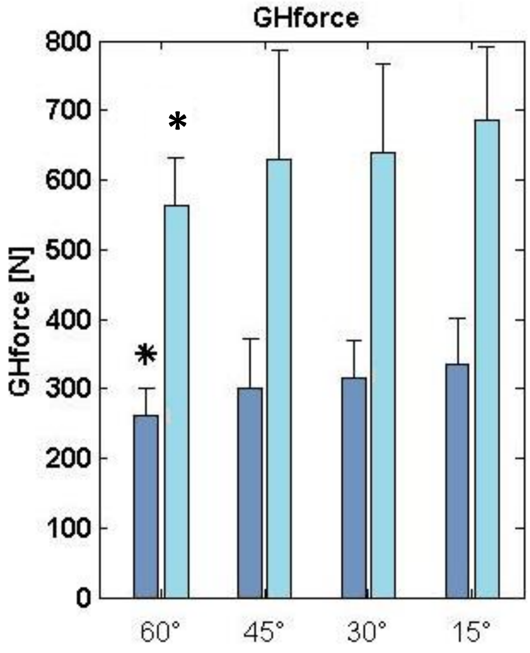


Backrest inclination



Glenohumeral contact force

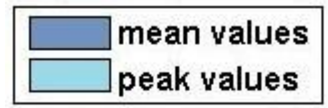


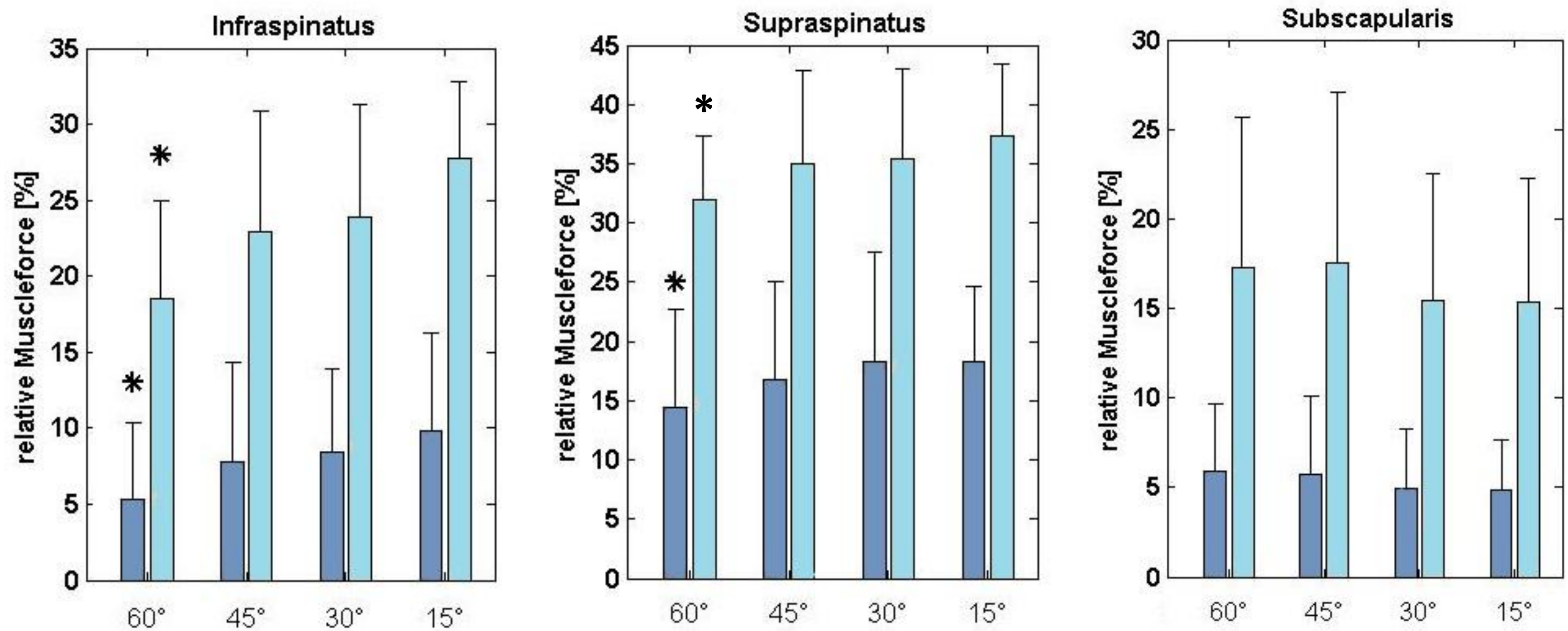


* = significant differences between setups

Backrest inclination

Muscle forces





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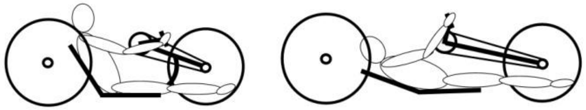
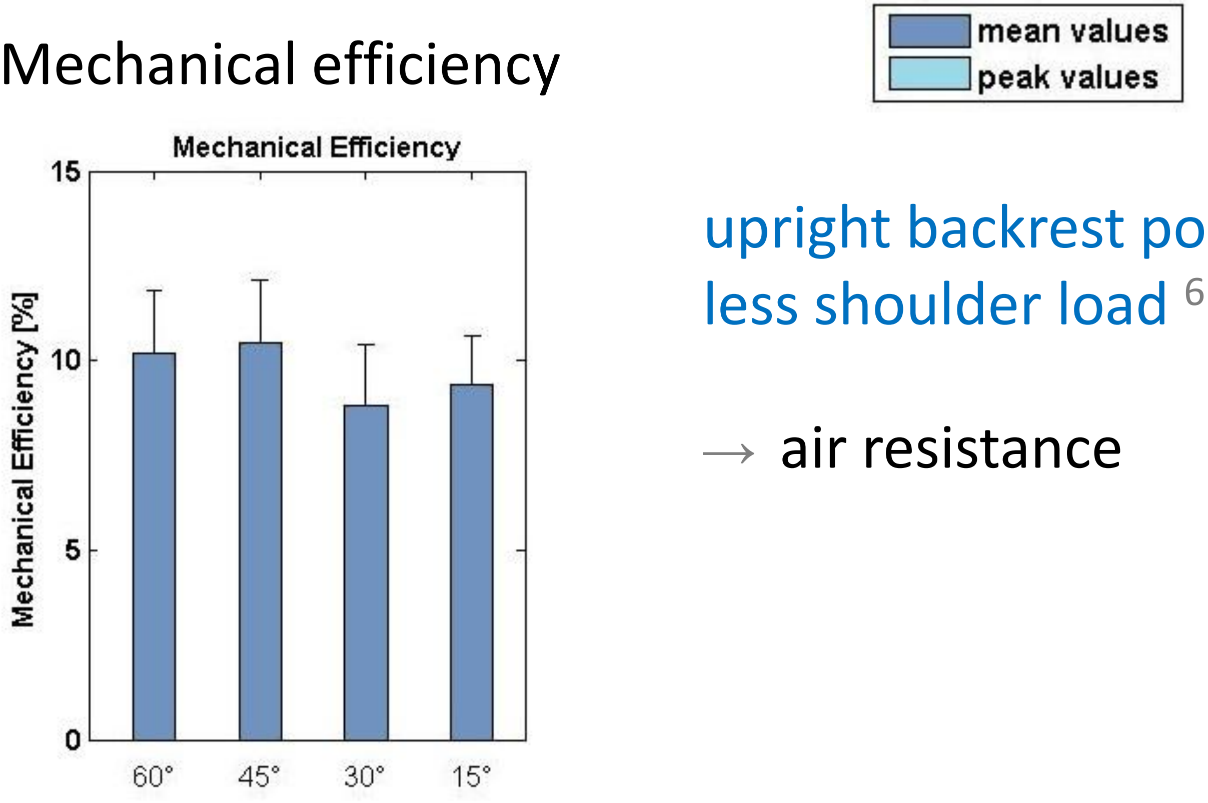
Backrest inclination



Mechanical efficiency

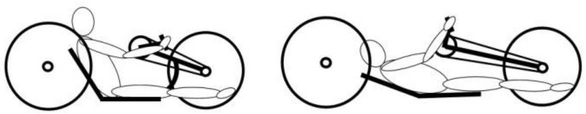


upright backrest position:
less shoulder load [6]

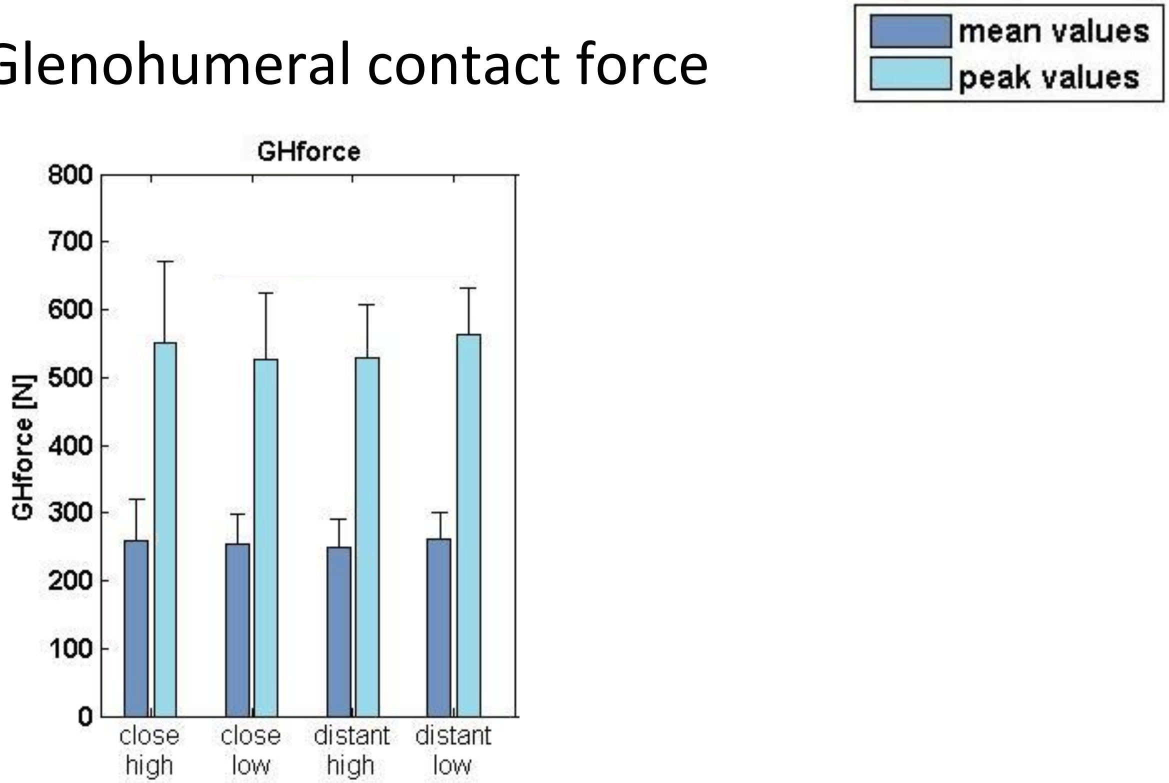
→ air resistance

[6] Arnet et al. The effect of crank position and backrest inclination on shoulder load and mechanical efficiency during handcycling. Submitted to the Scandinavian Journal of Medicine and Science in Sports.

Crank position



Glenohumeral contact force



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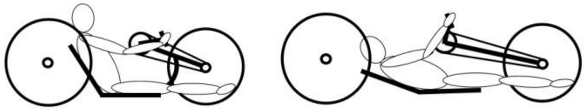
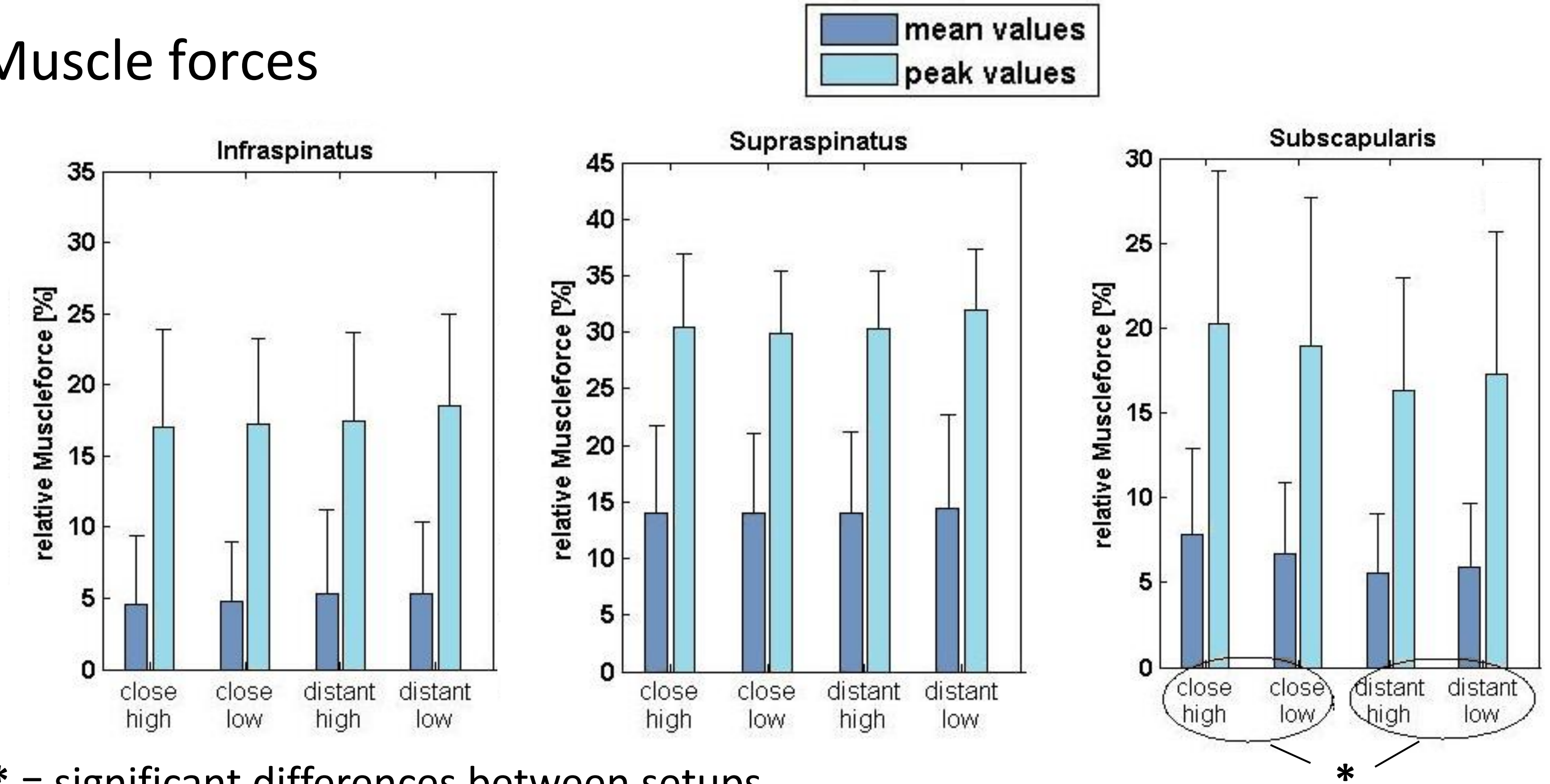
Crank position

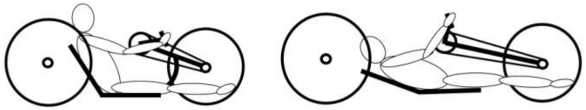


Muscle forces

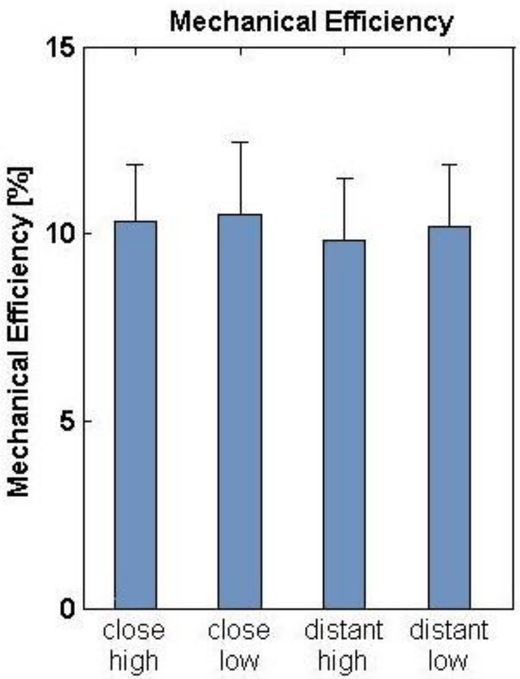


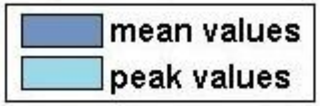
* = significant differences between setups

Crank position



Mechanical efficiency





distant crank position:
less load on the subscapularis [6]

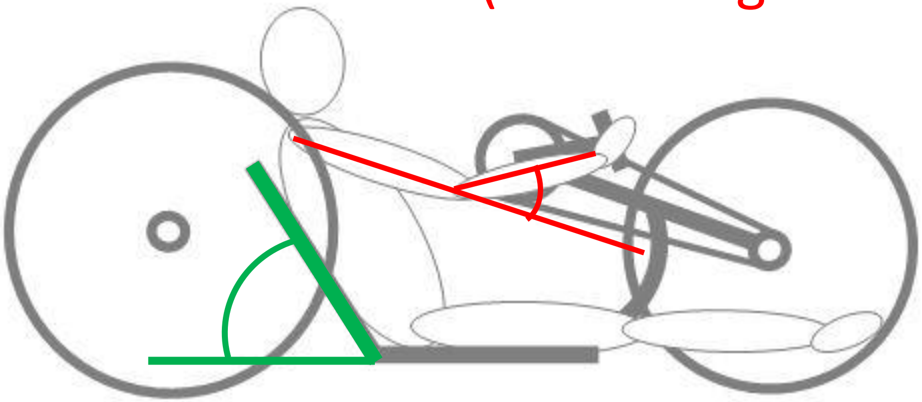
***** = significant differences between setups

[6] Arnet et al. The effect of crank position and backrest inclination on shoulder load and mechanical efficiency during handcycling. Submitted to the Scandinavian Journal of Medicine and Science in Sports.

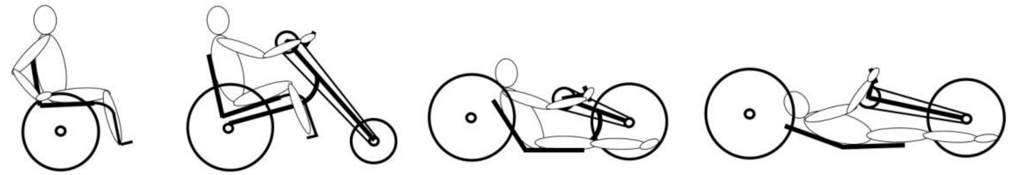
Optimal position

distant crank position
(elbow angle = 15°)

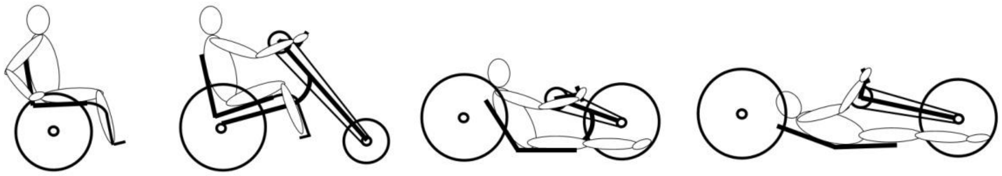
upright backrest
(inclination = 60°)



Conclusion

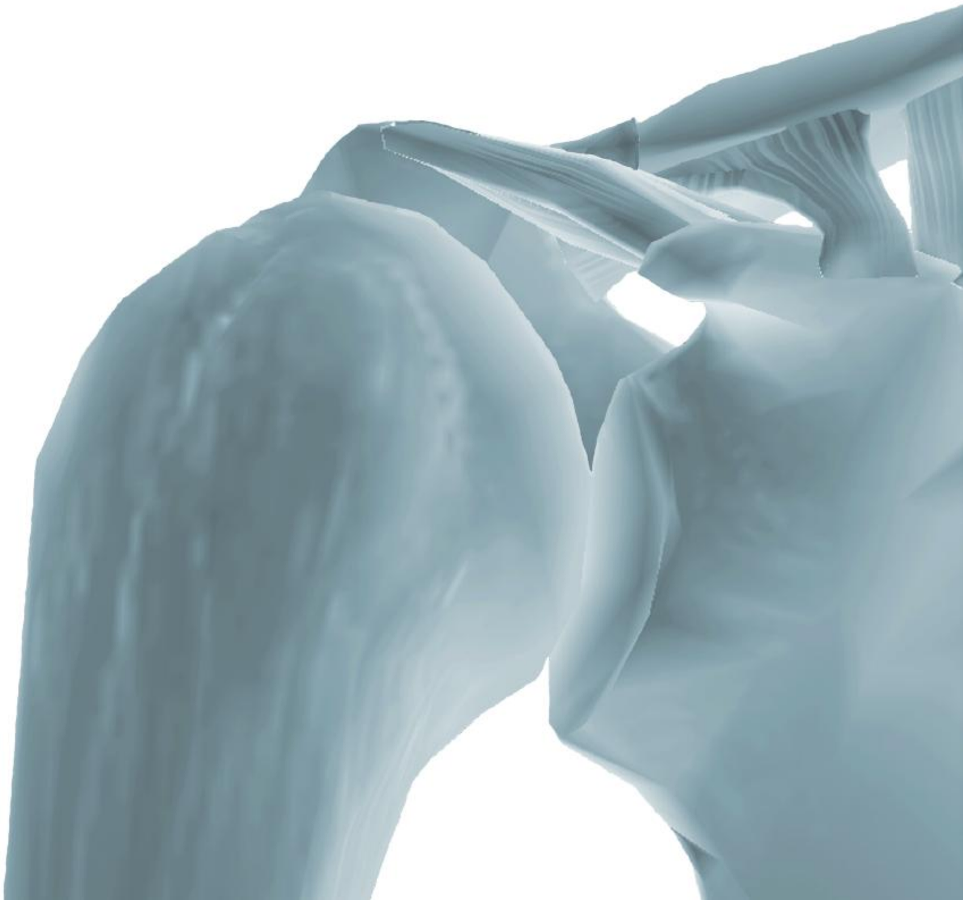


All in all the handbike is preferred for outdoor mobility over the manual handrim wheelchair. With an optimal adjustment to its user, the increased use of the handbike can prevent overuse injuries and improve the physical fitness and mobility of wheelchair dependent persons.



Thanks for the attention!

Questions?



Point of contact of the glenohumeral contact force