FITTING A WHEELCHAIR, BIOMECHANICS, AND DESIGN

CORRECT FITTING OF A WHEELCHAIR

Complications from improper fitting

Sitting habits

- Able bodied person – long period of sitting usually 1-2 hours, shifting weight all the time
- Disabled person may sit for 3 to 10 hours per day without repositioning

Complications due to poor posture

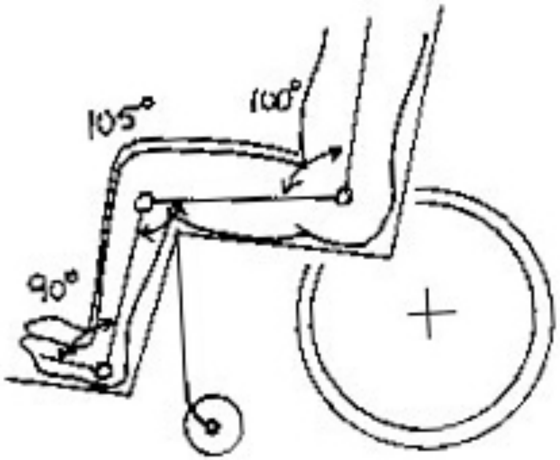
- Contractions and deformities
- Tissue breakdown
- Reduced performance and tolerance
- Urinary and respiratory infection
- Fatigue and discomfort

Correct posture?

Free Wheelchair Mission Chair
(www.doitfoundation.org)

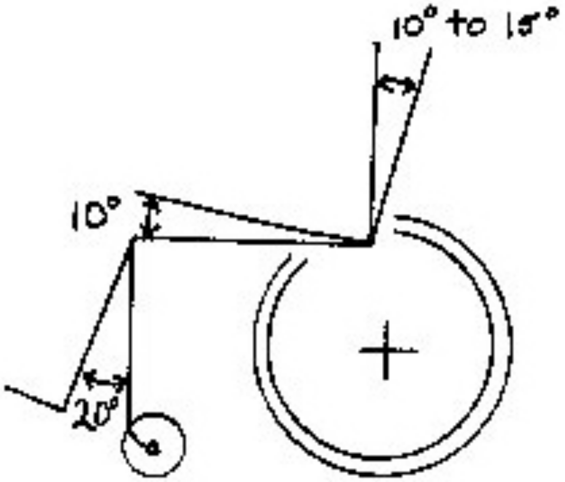
CORRECT FITTING OF A WHEELCHAIR
Correct anatomical and wheelchair positions

- Want to distribute weight over butt and thighs
- Only want 1.25cm clearance between butt and frame



Correct body position

Figures from (Mayall, 1995)



Correct wheelchair position

Wheelchair Foundation Chair
(www.kidswithoutborders.com)

CORRECT FITTING OF A WHEELCHAIR
Considerations during assessment

Considerations during prescription

- Diagnosis and prognosis
- Age
- Communication status
- Cognitive function
- Perceptual function
- Physical ability
- **Level of independence in activities during daily living**
- Transfer ability and modality
- Mobility (ambulation and wheelchair mobility)
- Body weight
- Sensory status
- Presence of edema
- Leisure interests
- **Transportation to and from home**
- **Roughness of usage**
- Time spent in wheelchair daily

List from (Mayall, 1995)

Wheelchair Foundation in Tanzania

Tanzania Big Game Safari:

•Largest donator in Tanzania, giving away nearly 7,000 chairs so far.

•Said Wheelchair Foundation will give a chair to anyone who seems to need one – a loose requirement that may include people who are crawling on the ground to people who may walk with a crutch.

•Admitted they get so many chairs every year that after the first few hundred have been distributed, it is very difficult to find genuinely disabled people to whom they can give them.

Monduli Rehab Center:

•Criticized the WC Foundation and said wheelchairs should not be given out like candy.

•Because the village terrain is so rough, people should be encouraged to walk with crutches or braces, and WCs should be a last resort.

CORRECT FITTING OF A WHEELCHAIR
Cushioning and positioning

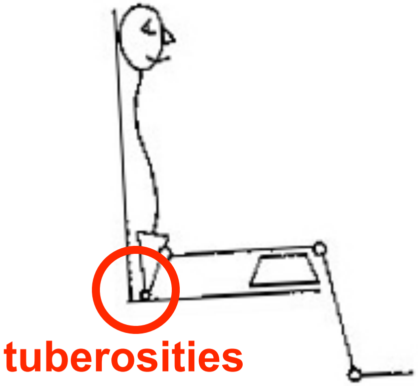


Figure 5-1. Pelvis positioning with a pre-ischial bar.

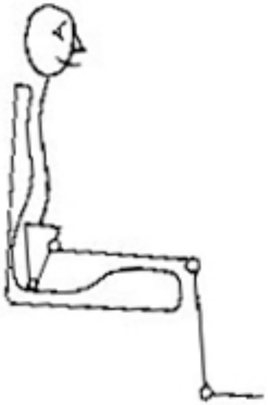


Figure 5-4. Pelvis positioning with contoured firm seat and back.

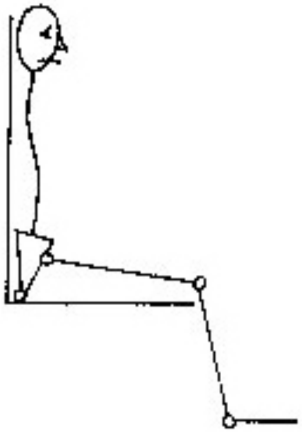


Figure 5-2. Pelvis positioning without a pre-ischial bar.

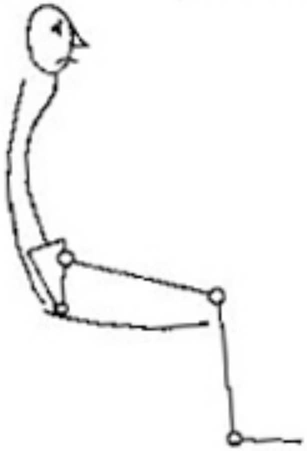


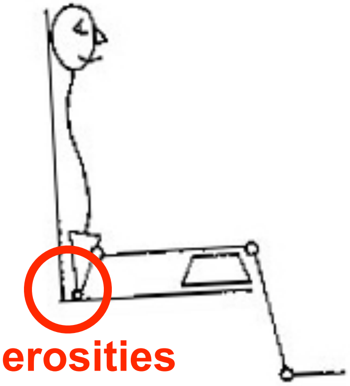
Figure 5-3. Pelvis positioning with sling seat and back.

Figures from (Mayall, 1995)

CORRECT FITTING OF A WHEELCHAIR
Cushioning and positioning

Pressure Sores

(Close eyes if squeamish)



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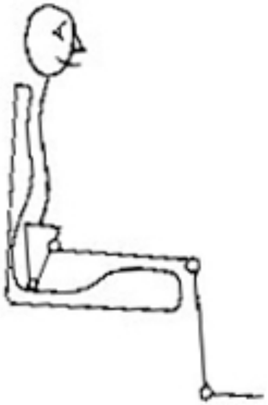

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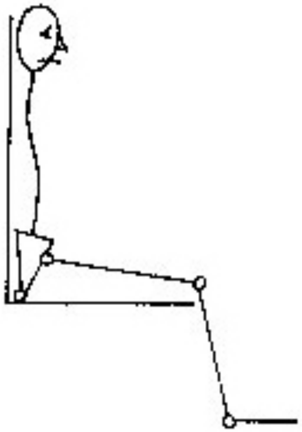

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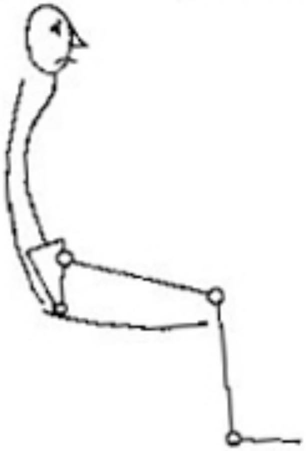

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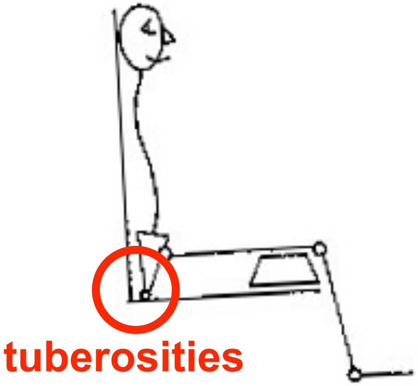
Figures from (Mayall, 1995)

CORRECT FITTING OF A WHEELCHAIR
Cushioning and positioning



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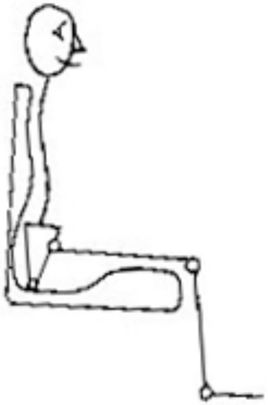

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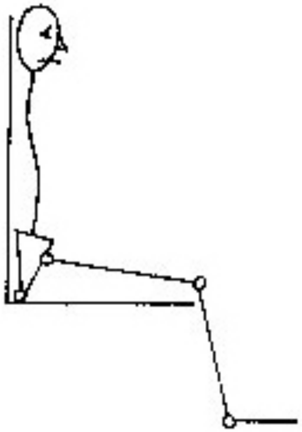

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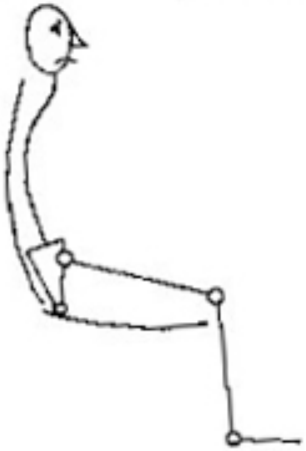

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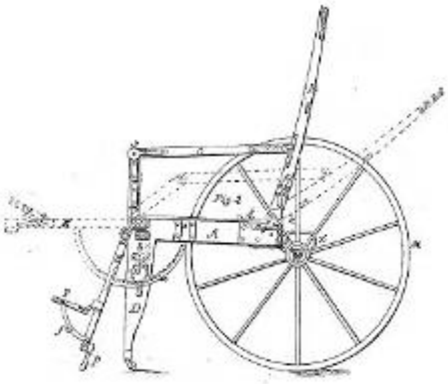
Pressure Sores

(Close eyes if squeamish)

WHEELCHAIR PROPULSION



First US wheelchair patent
A.P. Blunt, et. all., 1869

Example state-of-the-art
Quickie wheelchair, 2006

- Wheelchair propulsion 2-10% efficient (Woude et al, 1986, 1998)
- Optimal human chemical-mechanical whole body efficiency ~ 25% (Mark's STD Handbook, 1978)
  - Occurs at ½ max muscle force and ¼ max muscle speed
  - Optimal efficiency and max power output do not occur together → **Engage more muscles for more power**

UROP: Mario Bollini

Determine best system → Wheelchair propulsion project

- Determine the upper body motion that yields highest sustainable power at highest efficiency to deterministically design a wheelchair drive system

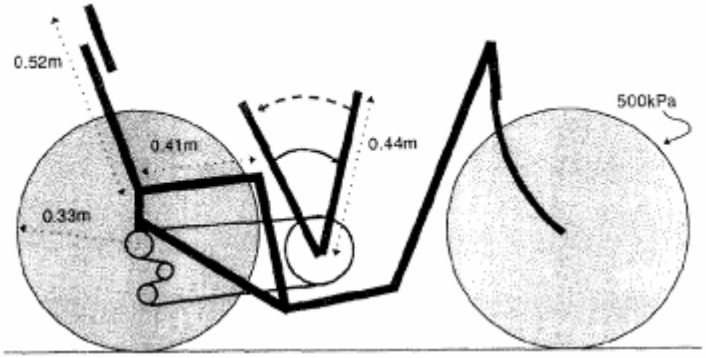
WHEELCHAIR PROPULSION RESEARCH

Previous work: **Power output measured from different drive systems**

Conventional chair

$P_{out} = 26.5W$

(van der Linden, et al, 1996)



Lever-powered tricycle

$P_{out} = 39.3W$

(van der Woude, et al, 1997)

Motivation: **To deterministically design a drive system for long and short distance travel, the maximum available efficient power should dictate the design**

$$\eta P_{human} = \eta T_{human}\omega_{human} = P_{out} = F_{resist}V_{device} = F_{resist}R_{wheel}\omega_{wheel}$$

$$\frac{\omega_{wheel}}{\omega_{human}} = Gear\ Ratio$$

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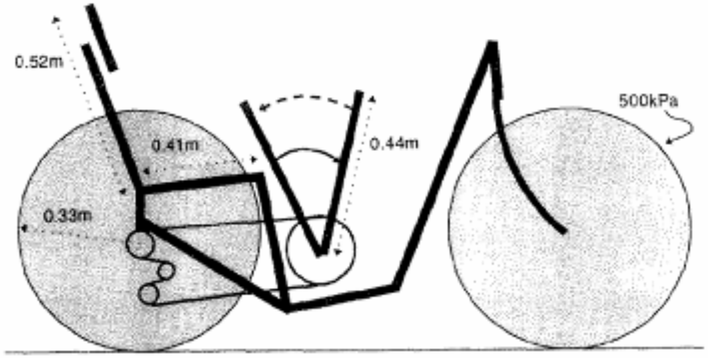

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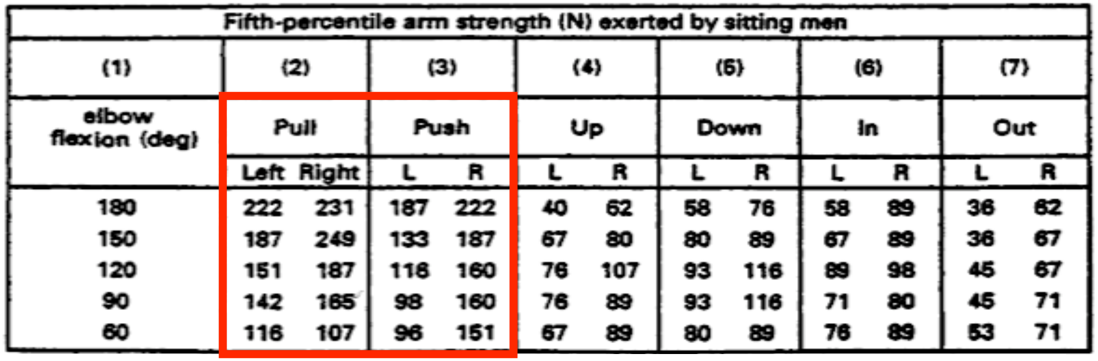
$$\eta \underbrace{\boxed{P_{human}}}_{\text{TBD}} = \eta T_{human}\omega_{human} = P_{out} = F_{resist}V_{device} = \underbrace{\boxed{F_{resist}}}_{\text{dictated by environment}} R_{wheel} \underbrace{\boxed{\omega_{wheel}}}_{\text{calculated}}$$

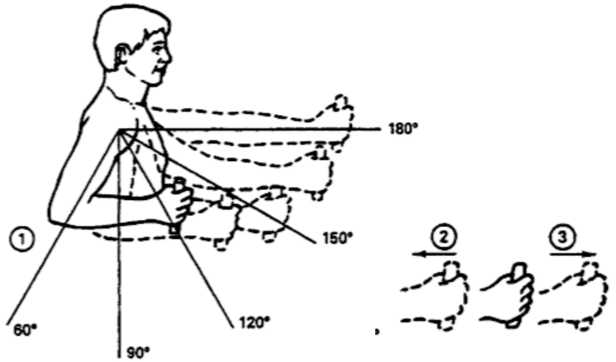
$$\frac{\omega_{wheel}}{\omega_{human}} = \underbrace{\boxed{Gear\ Ratio}}_{\text{tune through design}}$$

WHEELCHAIR PROPULSION RESEARCH



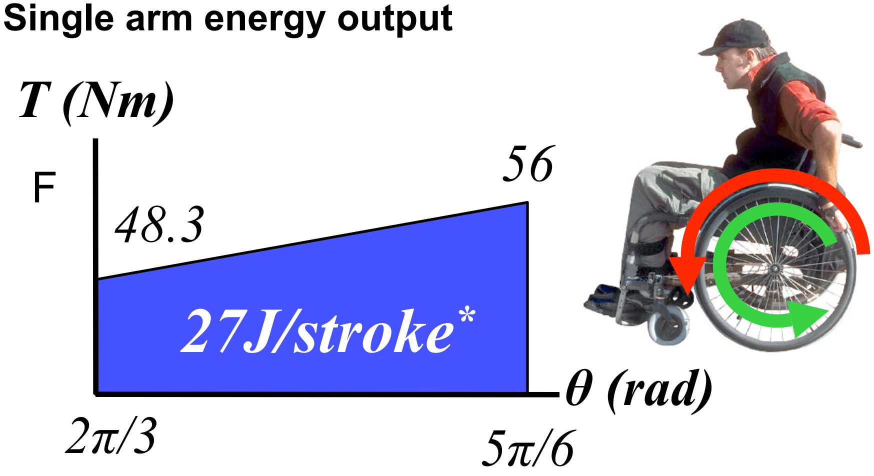
Fifth-percentile arm strength (N) exerted by sitting men												
(1)	(2)		(3)		(4)		(5)		(6)		(7)	
elbow flexion (deg)	Pull		Push		Up		Down		In		Out	
	Left	Right	L	R	L	R	L	R	L	R	L	R
180	222	231	187	222	40	62	58	76	58	89	36	62
150	187	249	133	187	67	80	80	89	67	89	36	67
120	151	187	116	160	76	107	93	116	89	98	45	67
90	142	165	98	160	76	89	93	116	71	80	45	71
60	116	107	96	151	67	89	80	89	76	89	53	71

Upper body biomechanics data

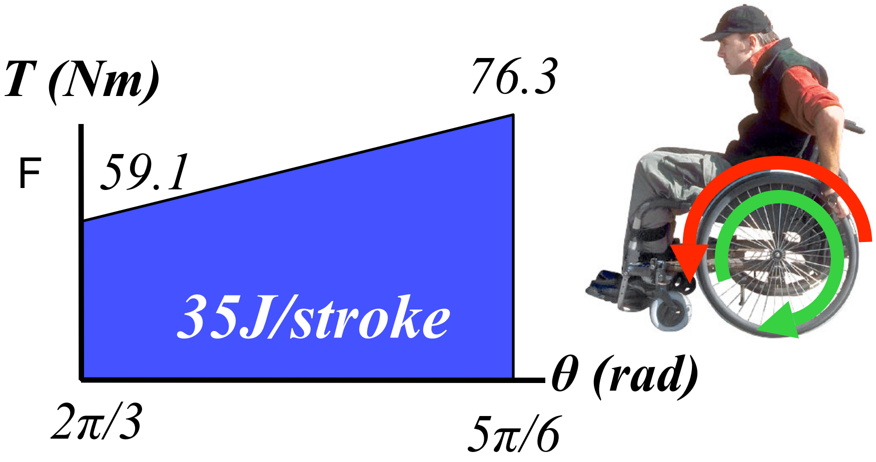


(Shigley, Mischke, 1996)

Single arm energy output



Conventional wheelchair propulsion

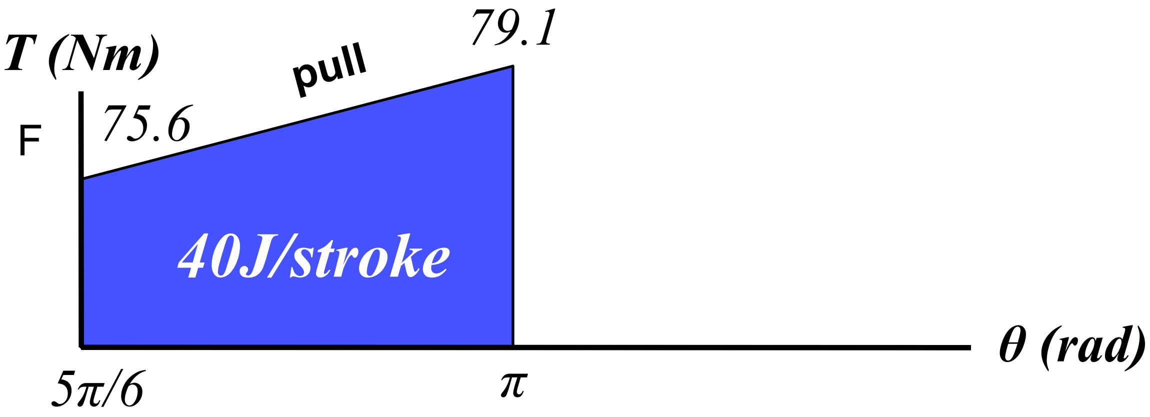


Opposed handrim-wheel rotation

*2% error from van der Linden, et al, 1996

WHEELCHAIR PROPULSION RESEARCH

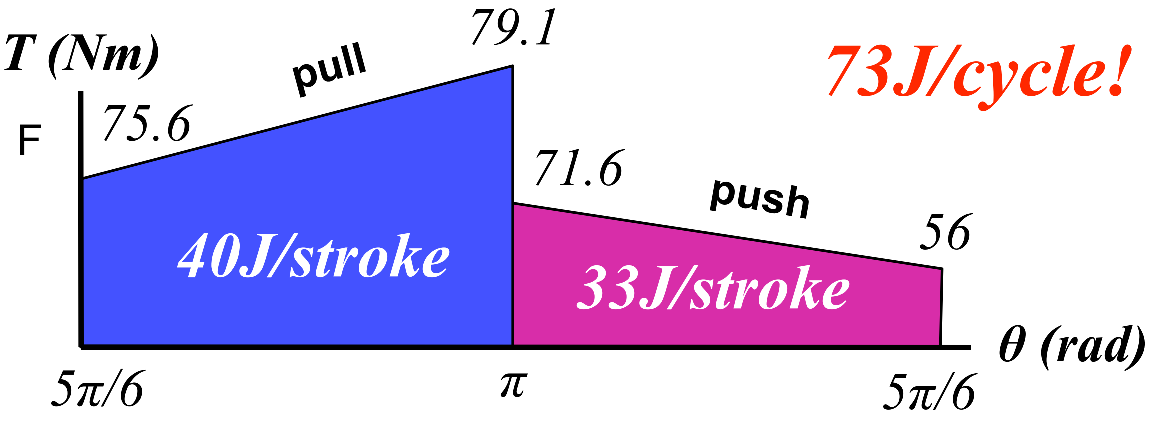
Single arm energy output



Rowing-motion propulsion

WHEELCHAIR PROPULSION RESEARCH

Single arm energy output



Rowing-motion propulsion

WHEELCHAIR PROPULSION RESEARCH

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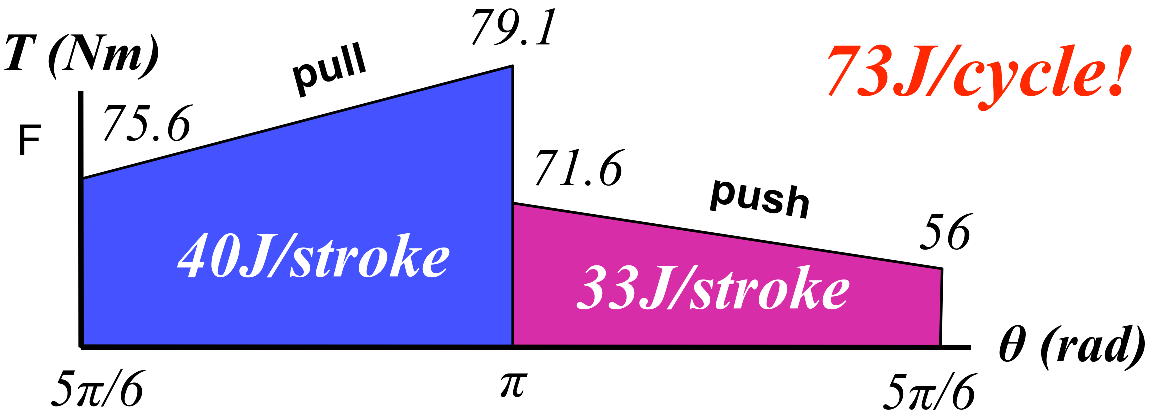

Rowing-motion propulsion

Additional questions

- What unidentified upper body motions can give high power output
- How different disabilities affect range of motion
- What type of resistance forces will be encountered depending on the environment

Unidentified high-power motions?

THE LEVERAGED FREEDOM CHAIR (LFC)

Project aim:

Create a mobility aid that can fulfill the needs of people with disabilities in developing countries

LFC Requirements:

- Capable of long-distance travel (~5km/day) on rough terrain
- Small and mobile enough to use within the home

MOTIVATION

Existing products do not fully provide mobility

- Wheelchairs are difficult to propel off road
- Tricycles are too big to use in the home

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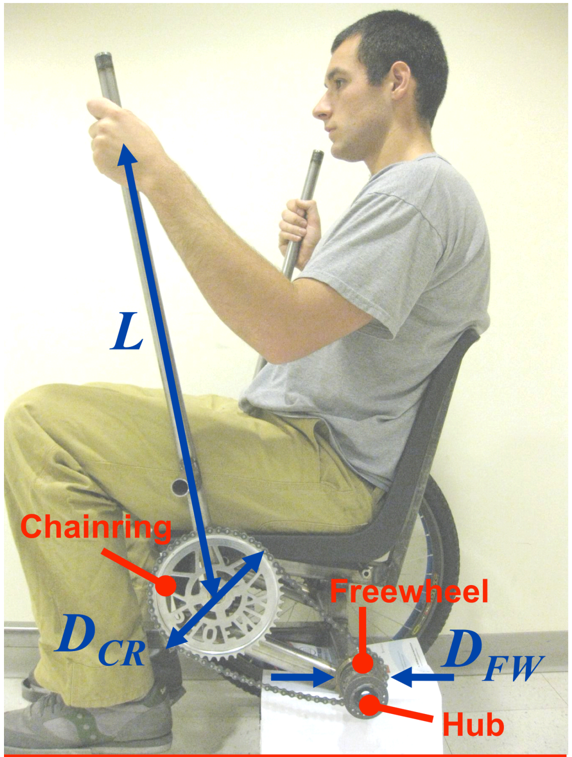
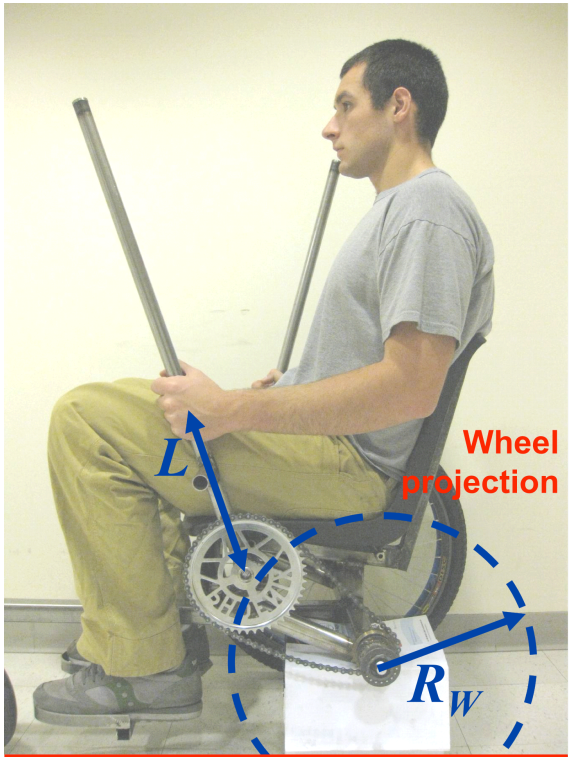
SOLUTION

Fixed gear ratio, variable speed drivetrain



Low Gear



High Gear

Drivetrain performance

Difference b/w chair velocity (V_{Chair}) and hand velocity (V_{Hand})

$$\boxed{\frac{V_{Chair}}{V_{Hand}} = \frac{D_{CR}R_W}{D_{FW}L}}$$

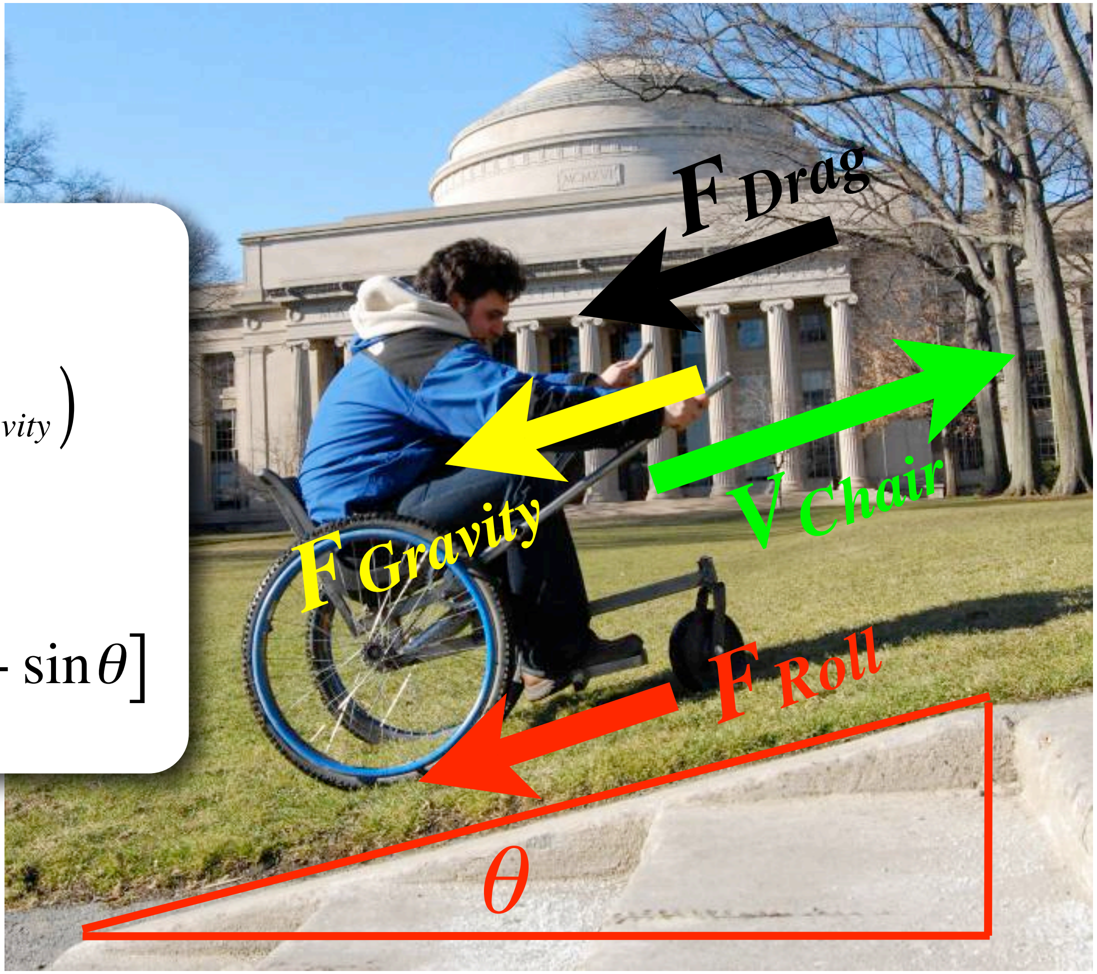
- Enables drivetrain to be made from bike components
- LFC can be built on a wheelchair platform

MOBILITY LAB

ANALYSIS

Power balance during propulsion

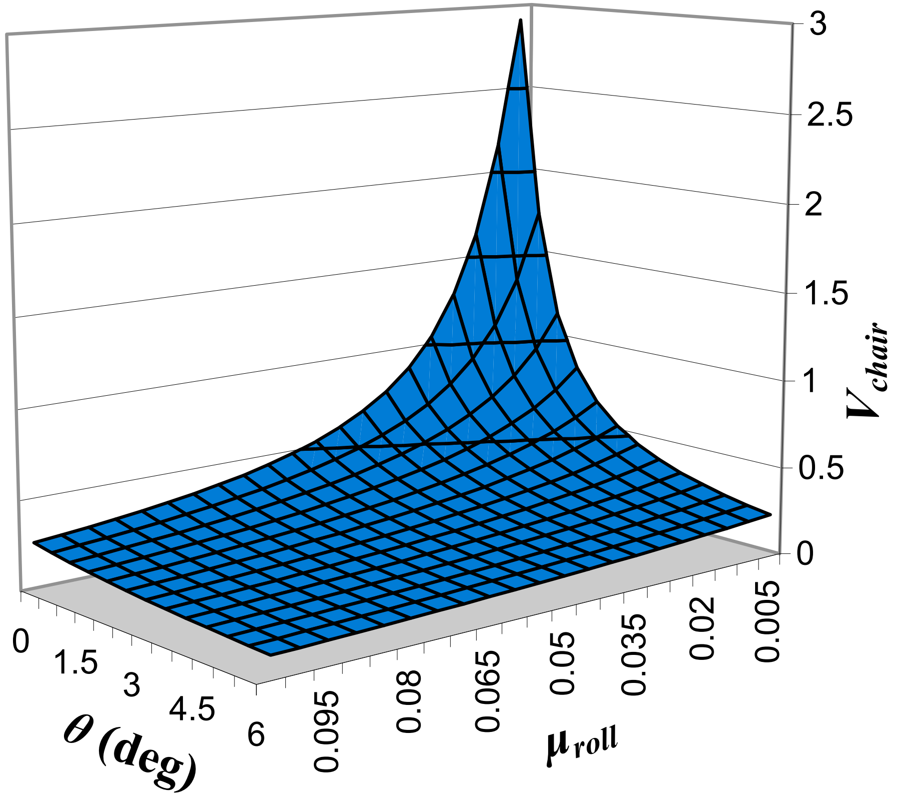
$$
\begin{aligned}
P_{Human} &= P_{Drag} + P_{Roll} + P_{Gravity} \\
&= V_{Chair}\left(F_{Drag} + F_{Roll} + F_{Gravity}\right) \\
&= C_D \frac{1}{2} \rho_{Air} A \left(V_{Chair}\right)^3 \\
&\quad + mg\left(V_{Chair}\right)\left[\mu_{Roll}\cos\theta + \sin\theta\right]
\end{aligned}
$$



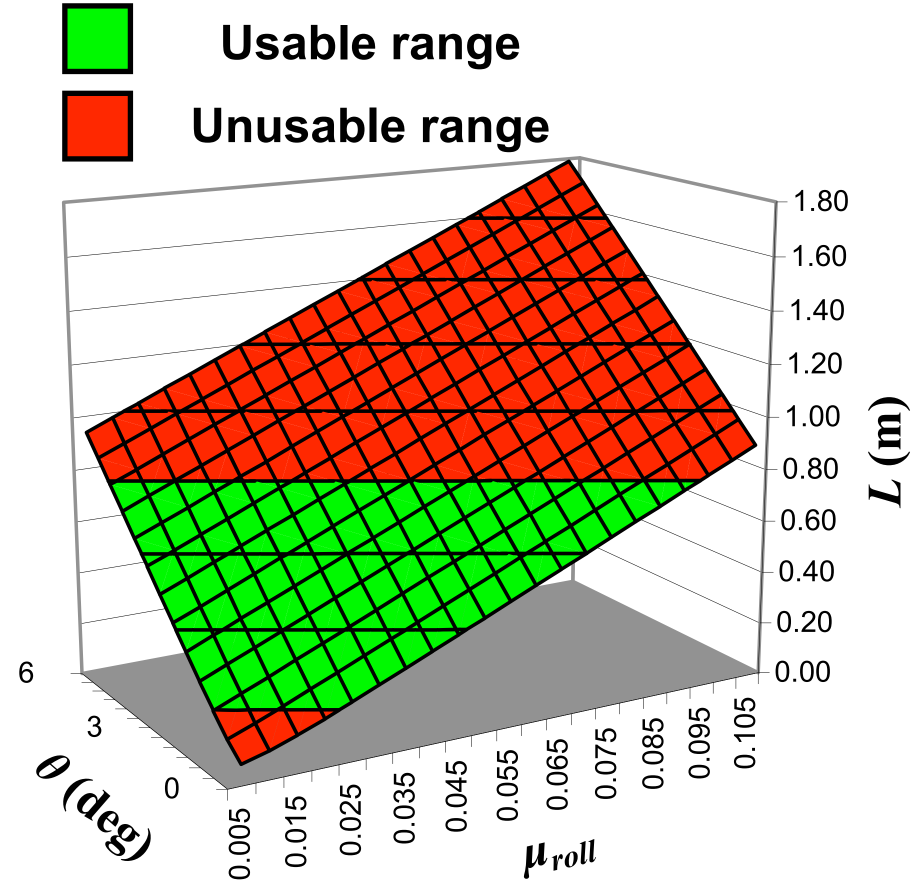
MOBILITY LAB

LEVER DESIGN: EFFICIENCY

Pushing power output at maximum efficiency = 19.6W (58N at 0.38m/s) (Woude, 1997)



Anticipated velocity



Required lever length

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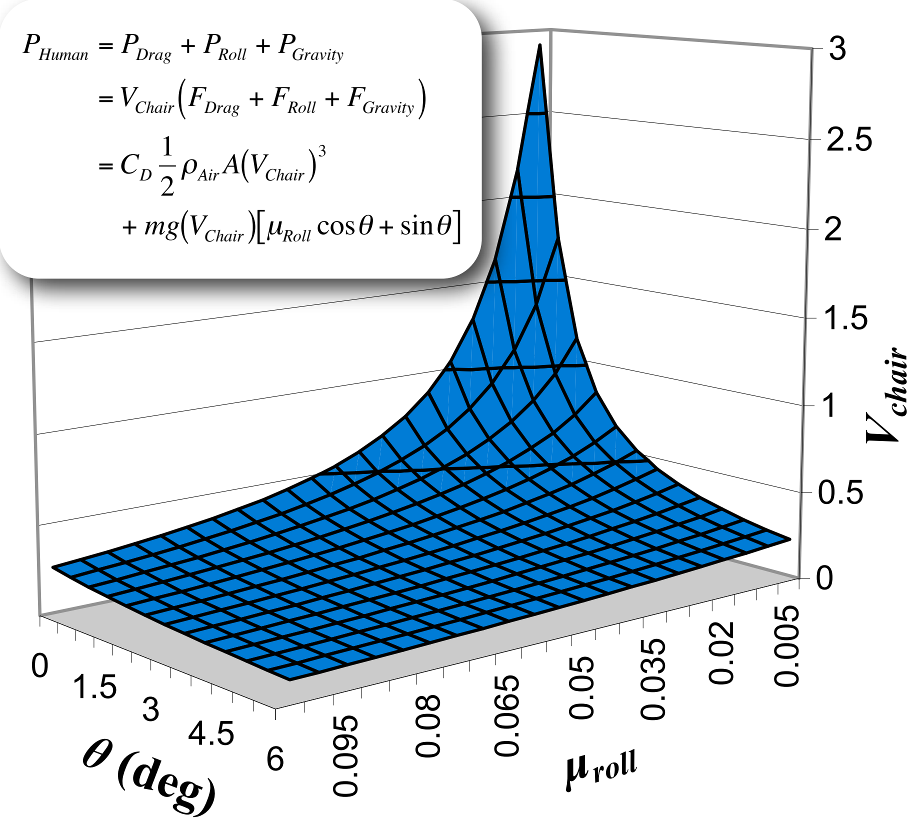

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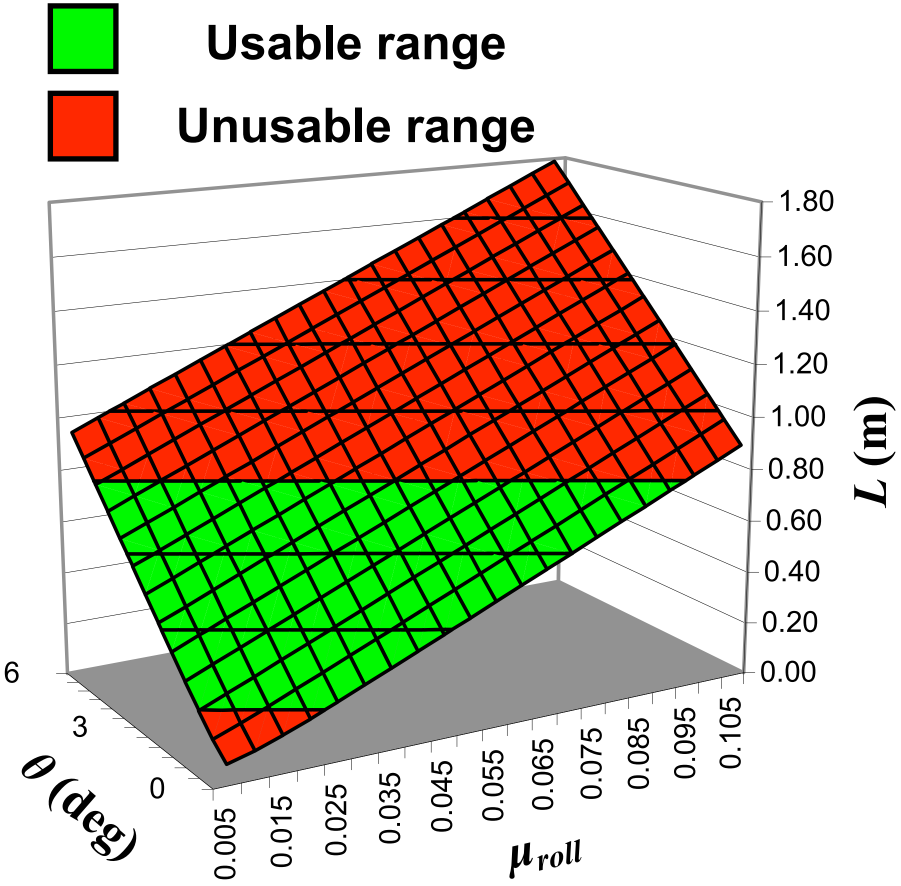

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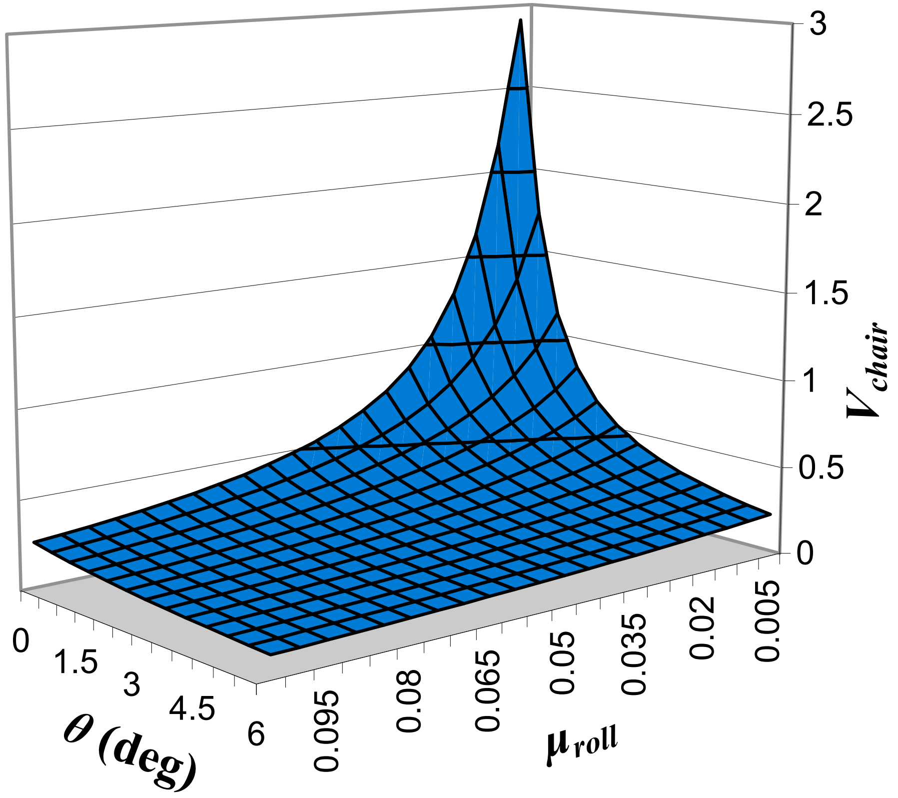
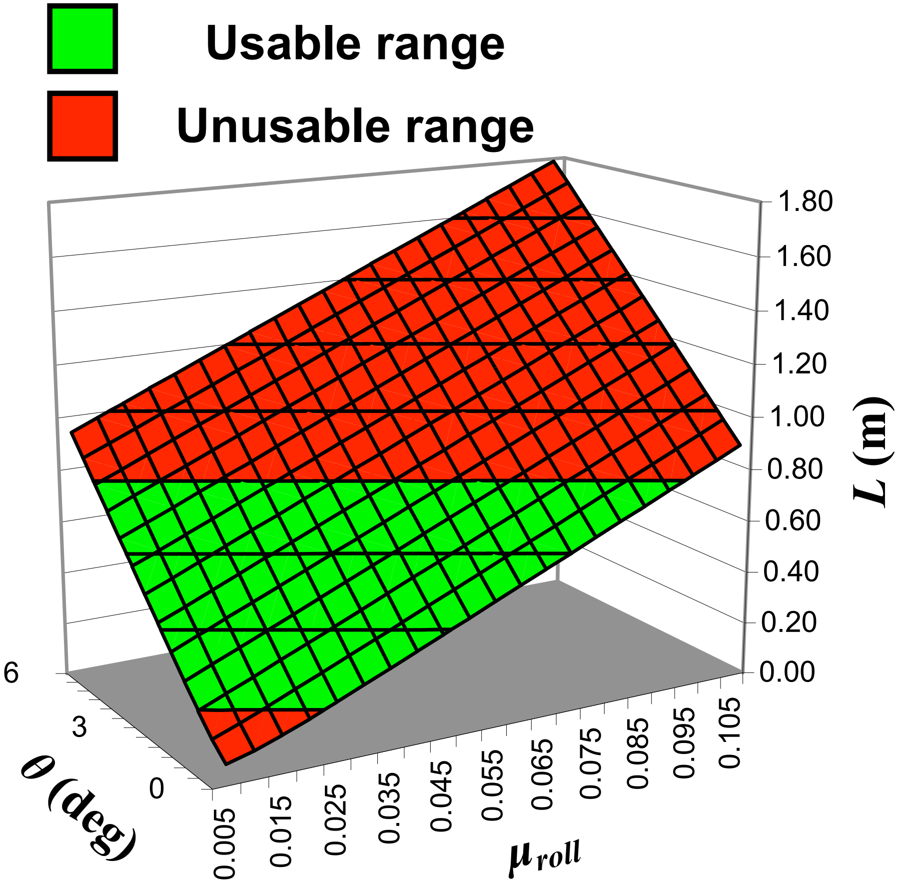


Anticipated velocity



Required lever length

MOBILITY LAB

LEVER DESIGN: PEAK FORCE

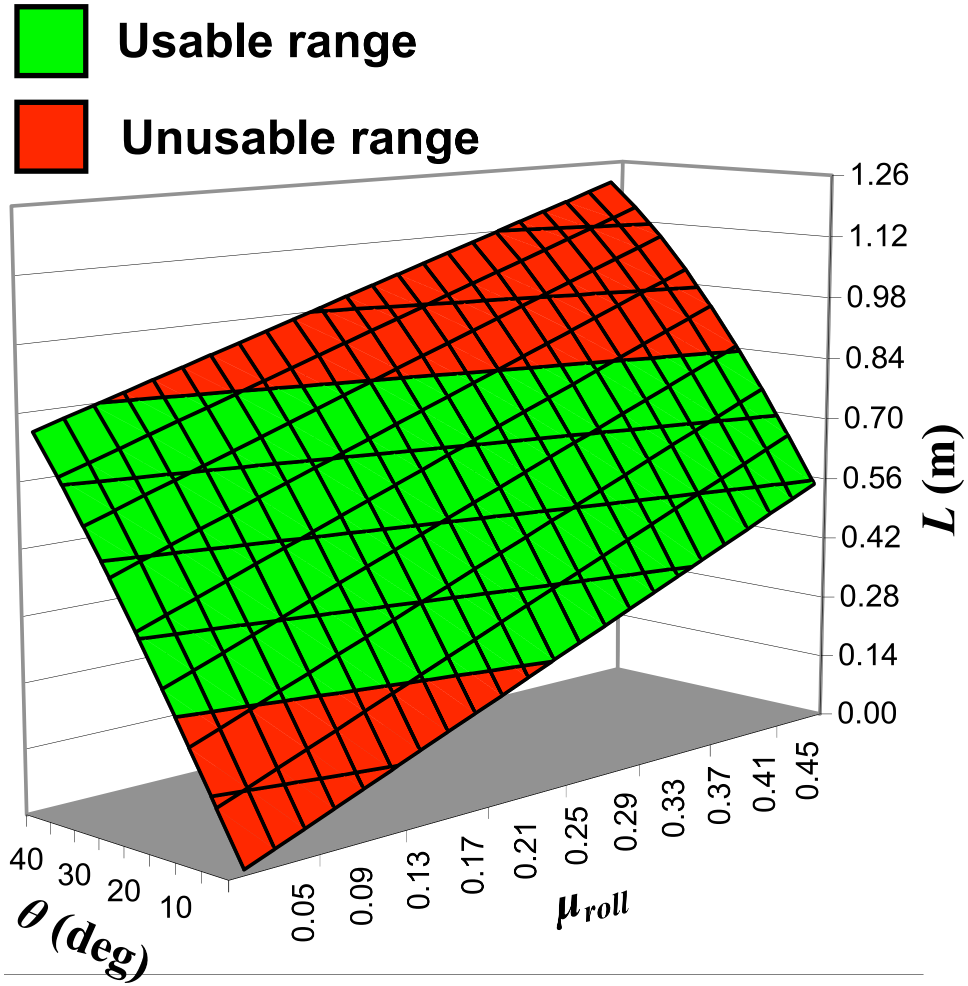
Peak pushing force = 356N (Cott, 1972)

Force balance at stall

$$F_{Resist} = mg\left[\mu_{Roll}\cos\theta + \sin\theta\right]$$

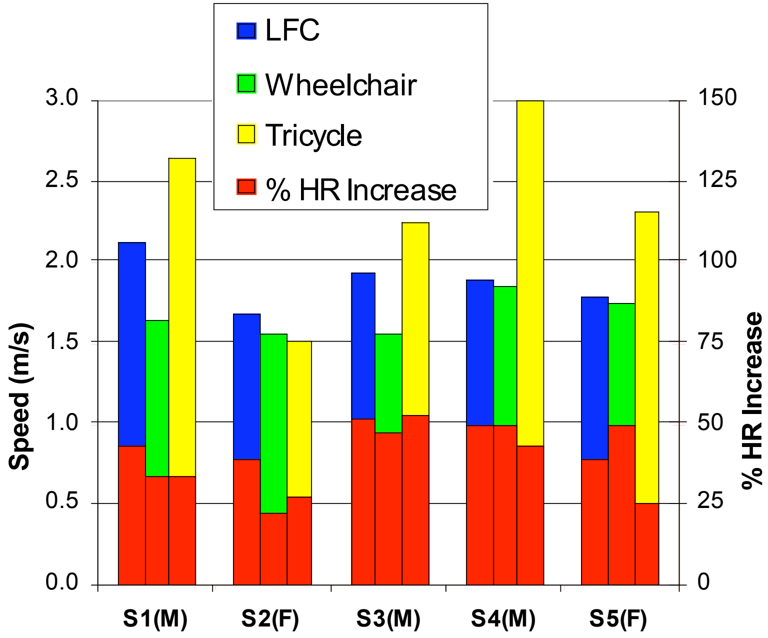
Punchline:

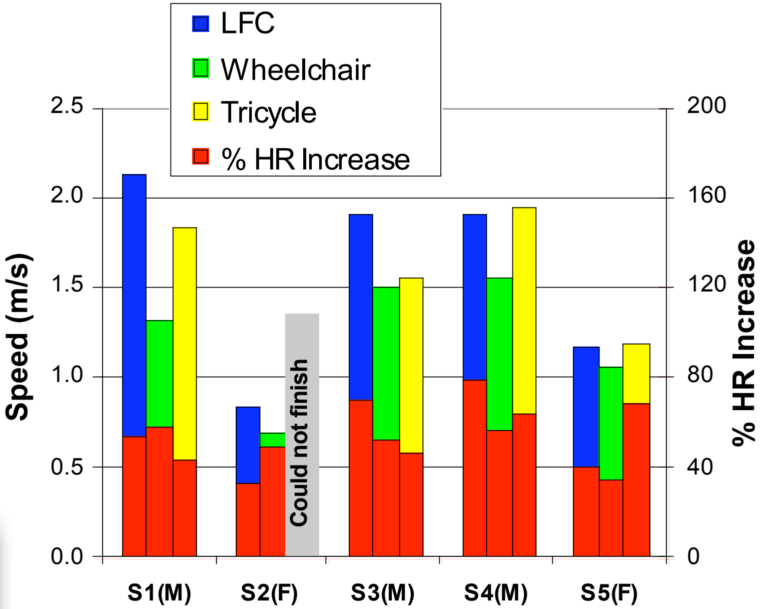
Lever lengths from 22cm to 86cm enable the user to go through most any terrain



Required lever length

COMPARATIVE TESTING - ABLE BODIED





Endurance test

0.87km on smooth ground

- LFC : 1.89m/s
- Wheelchair: 11.7% slower
- Tricycle: 24.3% faster

Hill climb test

1:12 slope sections, overall 2.9m rise, 42.1m run

- LFC : 1.59m/s
- Wheelchair: 22.7% slower
- Tricycle: 17.9% slower

PERFORMANCE TESTING - ABLE BODIED

MOBILITY LAB

PERFORMANCE TESTING - ABLE BODIED

PERFORMANCE TESTING - EAST AFRICA

PERFORMANCE TESTING - EAST AFRICA

MOBILITY LAB

AFRICAN TRIAL RESULTS - SURVEY

Chart Key

ID = Indoors

P = Pavement

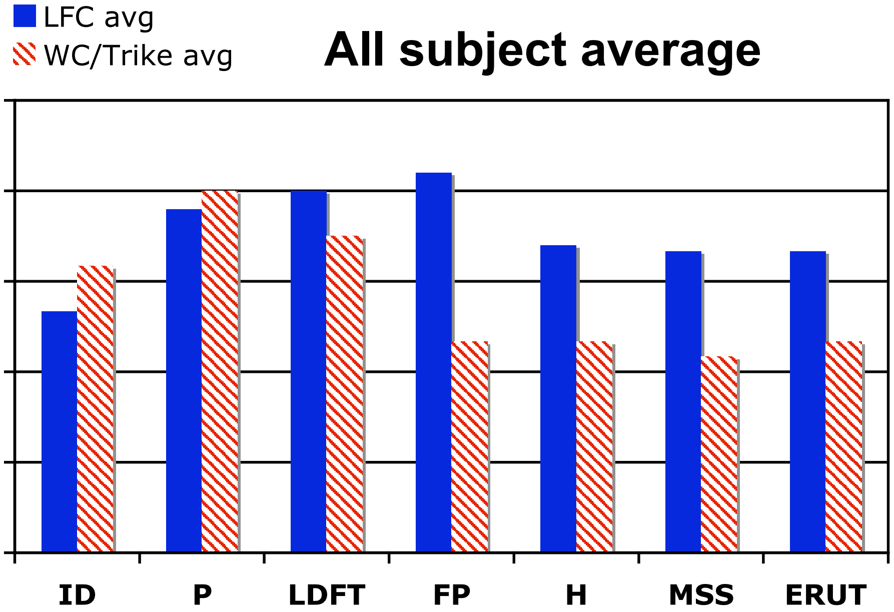
LDFT = Long distance, flat terrain

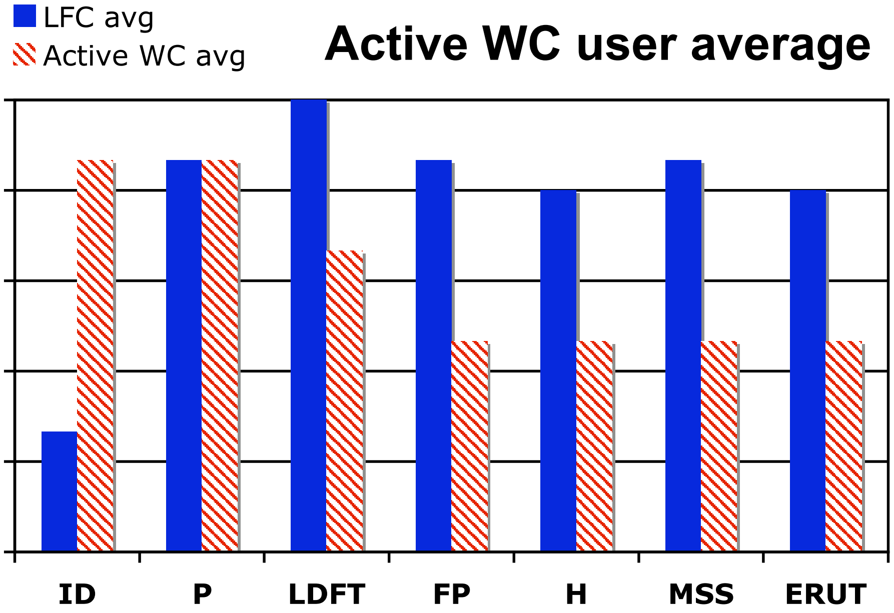
FP = Footpaths

H = Hills

MSS = Mud/soft soil

ERUT = Extremely rough, uneven terrain





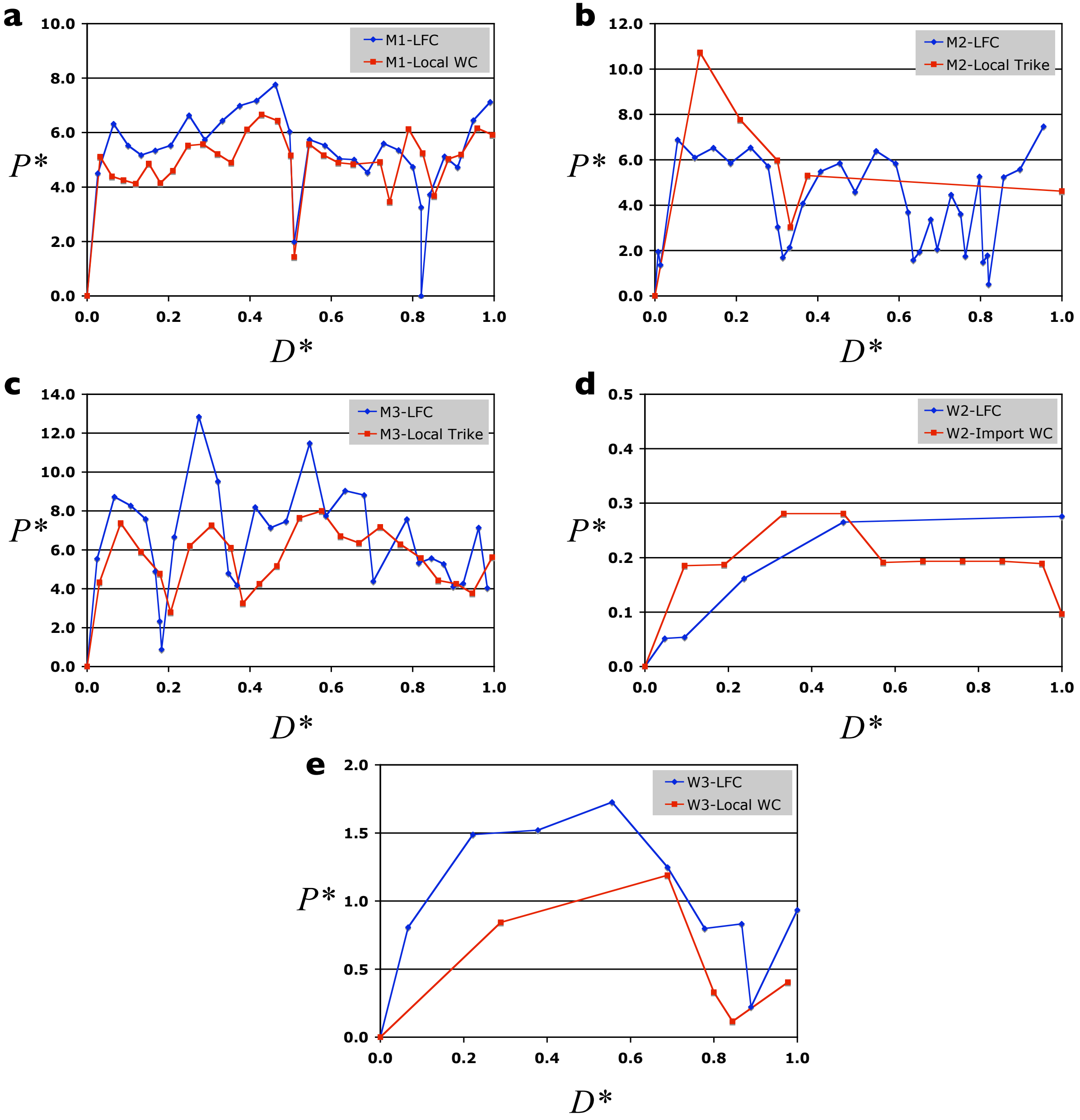
AFRICAN TRIAL RESULTS - PERFORMANCE

Performance metrics

$$D^* = \frac{\text{Distance traveled}}{\text{Total distance}}$$

$$P^* = \frac{\mu m g V}{HR^*}$$

$$HR^* = \frac{HR_{current}}{HR_{resting}}$$



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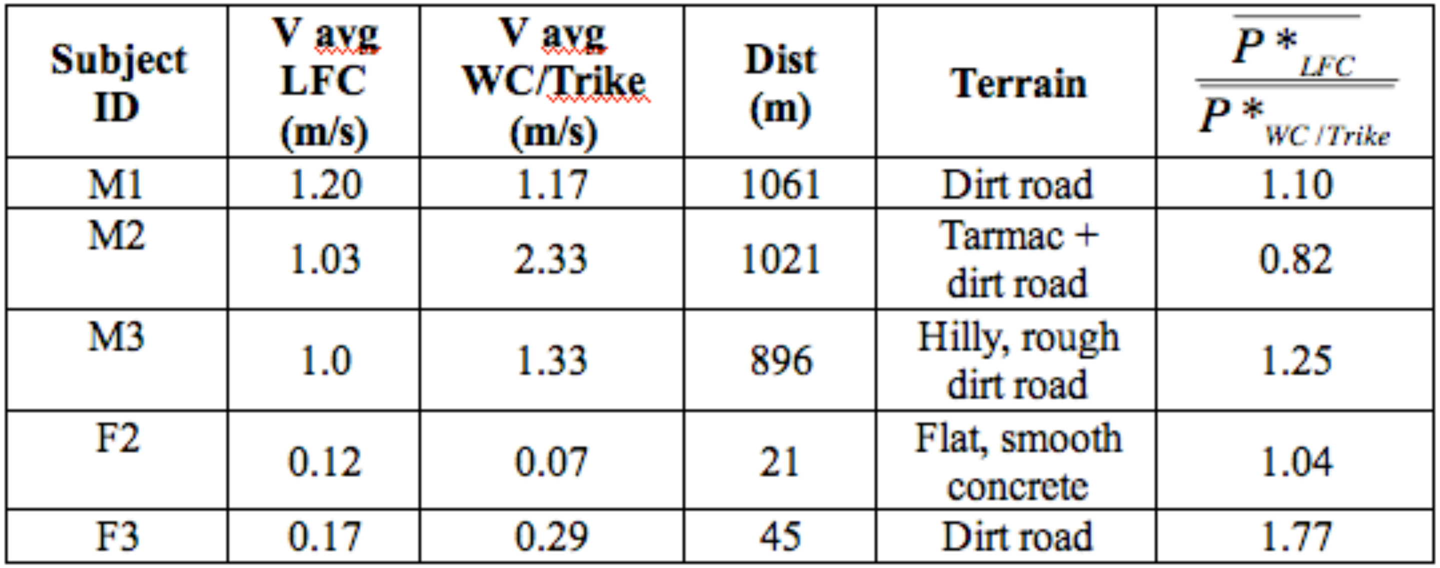

Subject ID	V avg LFC (m/s)	V avg WC/Trike (m/s)	Dist (m)	Terrain	$\frac{\overline{P^*_{LFC}}}{\overline{P^*_{WC/Trike}}}$
M1	1.20	1.17	1061	Dirt road	1.10
M2	1.03	2.33	1021	Tarmac + dirt road	0.82
M3	1.0	1.33	896	Hilly, rough dirt road	1.25
F2	0.12	0.07	21	Flat, smooth concrete	1.04
F3	0.17	0.29	45	Dirt road	1.77

Performance metrics

$$P^* = \frac{\mu m g V}{HR^*}$$

$$D^* = \frac{\text{Distance traveled}}{\text{Total distance}}$$

$$HR^* = \frac{HR_{current}}{HR_{resting}}$$

HOMEWORK

- Reading from Positioning in a Wheelchair
- Have second group meeting, define Functional Requirements and project scope, and send to Mentors and Community Partners for Review
- Pick first presentation day and discuss format