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

Correct wheelchair position

Figures from (Mayall, 1995)

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

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

Figures from (Mayall, 1995)
CORRECT FITTING OF A WHEELCHAIR
Cushioning and positioning

Pressure Sores
(Close eyes if squeamish)

Figures from (Mayall, 1995)
CORRECT FITTING OF A WHEELCHAIR
Cushioning and positioning

Pressure Sores
(Close eyes if squeamish)

Figures from (Mayall, 1995)
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

**UROP: Mario Bollini**

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

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

\[ \frac{\omega_{\text{wheel}}}{\omega_{\text{human}}} = \text{Gear Ratio} \]
Motivation: To deterministically design a drive system for long and short distance travel, the maximum available efficient power should dictate the design.

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

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)
Single arm energy output

**Conventional wheelchair propulsion**

*T (Nm)*

\[
\begin{align*}
F &= 48.3 \\
\theta (\text{rad}) &= 5\pi/6 \\
\end{align*}
\]

27J/stroke*

\[
\begin{align*}
\theta (\text{rad}) &= 5\pi/6 \\
\end{align*}
\]

76.3

\[
\begin{align*}
\theta (\text{rad}) &= 5\pi/6 \\
\end{align*}
\]

**Opposed handrim-wheel rotation**

*T (Nm)*

\[
\begin{align*}
F &= 59.1 \\
\theta (\text{rad}) &= 5\pi/6 \\
\end{align*}
\]

35J/stroke

*2% error from van der Linden, et al, 1996*
Single arm energy output

$$T \text{ (Nm)}$$

$$F$$

$$40 \text{J/stroke}$$

5\(\pi/6\) → \(\pi\)

Rowing-motion propulsion

WHEELCHAIR PROPULSION RESEARCH
Single arm energy output

Rowing-motion propulsion

$T (Nm)$

$\theta$ (rad)

$73J/cycle!$

$F$

40J/stroke

33J/stroke

79.1

71.6

56

5$\pi$/6

$\pi$

$5\pi$/6

$75.6$

$\frac{5\pi}{6}$

$\frac{\pi}{6}$

WHEELCHAIR PROPULSION RESEARCH
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
Existing products do not fully provide mobility

- Wheelchairs are difficult to propel off road
- Tricycles are too big to use in the home
Fixed gear ratio, variable speed drivetrain

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

\[
\frac{V_{Chair}}{V_{Hand}} = \frac{D_{CR} R_W}{D_{FW} L}
\]

• Enables drivetrain to be made from bike components
• LFC can be built on a wheelchair platform
Power balance during propulsion

\[ P_{\text{Human}} = P_{\text{Drag}} + P_{\text{Roll}} + P_{\text{Gravity}} \]

\[ = V_{\text{Chair}} \left( F_{\text{Drag}} + F_{\text{Roll}} + F_{\text{Gravity}} \right) \]

\[ = C_D \frac{1}{2} \rho_{\text{Air}} A (V_{\text{Chair}})^3 \]

\[ + mg(V_{\text{Chair}})[\mu_{\text{Roll}} \cos \theta + \sin \theta] \]
Pushing power output at maximum efficiency = 19.6W (58N at 0.38m/s) (Woude, 1997)

Anticipated velocity

Required lever length
LEVER DESIGN: EFFICIENCY

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

\[
P_{\text{Human}} = P_{\text{Drag}} + P_{\text{Roll}} + P_{\text{Gravity}}
= V_{\text{Chair}} \left( F_{\text{Drag}} + F_{\text{Roll}} + F_{\text{Gravity}} \right)
= C_D \frac{1}{2} \rho_{\text{Air}} A (V_{\text{Chair}})^3
+ m g (V_{\text{Chair}}) \left[ \mu_{\text{Roll}} \cos \theta + \sin \theta \right]
\]

Anticipated velocity

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

Anticipated velocity

Required lever length
Peak pushing force = 356N (Cott, 1972)

Force balance at stall

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

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

Hill climb test
1:12 slope sections, overall 2.9m rise, 42.1m run
- LFC: 1.59 m/s
- Wheelchair: 22.7% slower
- Tricycle: 17.9% slower
### Chart Key

- **ID** = Indoors
- **P** = Pavement
- **LDFT** = Long distance, flat terrain
- **FP** = Footpaths
- **H** = Hills
- **MSS** = Mud/soft soil
- **ERUT** = Extremely rough, uneven terrain

---

#### All subject average

<table>
<thead>
<tr>
<th></th>
<th>LFC avg</th>
<th>WC/Trike avg</th>
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<tbody>
<tr>
<td>ID</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDFT</td>
<td></td>
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<tr>
<td>FP</td>
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<tr>
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<td></td>
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<td>ERUT</td>
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#### Active WC user average

<table>
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<tr>
<th></th>
<th>LFC avg</th>
<th>Active WC avg</th>
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<tr>
<td>ERUT</td>
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</tr>
</tbody>
</table>
Performance metrics

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

\[ P^* = \frac{\mu mgV}{HR^*} \]

\[ HR^* = \frac{HR_{current}}{HR_{resting}} \]
## African Trial Results - Performance

### Performance Metrics

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

### Performance Metrics

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

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

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