Do you know how people move in their wheelchairs?
Measuring and describing real-world wheelchair use.

Sharon Eve Sonenblum, PhD
Georgia Institute of Technology
Learning Objectives

1. Participants will be able to describe 3 specifications to look for when sourcing technology for measuring wheelchair use.

2. Participants will be able to identify 3 individual characteristics associated with increased wheelchair mobility.

3. Participants will be able to distinguish between 2 measures of in-seat activity (pressure reliefs and activity level), and describe how often individuals with SCI perform these activities.
Learning Objectives - Unofficial

• Believe me that you should use commercially available equipment to track wheelchair use.
• Come to terms with how people actually move in their wheelchairs.
• Recognize the benefits to movement, and what you can do to promote movement.
# How far & over what duration do Manual Wheelchair Users Wheel

<table>
<thead>
<tr>
<th>Study</th>
<th>Population</th>
<th>Daily Distance</th>
<th>Daily Time</th>
<th>Daily Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karmarkar et al.</td>
<td>VA nursing homes</td>
<td>1.5 km</td>
<td>n/a</td>
<td>0.48 m/s</td>
</tr>
<tr>
<td>Levy et al.</td>
<td>Adults</td>
<td>1.45 km</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Tolerico et al.</td>
<td>Athletes</td>
<td>2.5 km</td>
<td>48 min</td>
<td>0.8 m/s</td>
</tr>
<tr>
<td>Cooper et al.</td>
<td>Children</td>
<td>1.6 km</td>
<td>n/a</td>
<td>0.67 m/s</td>
</tr>
<tr>
<td>Oyster et al.</td>
<td>SCI</td>
<td>1.9 km</td>
<td>47 min</td>
<td>0.63 m/s</td>
</tr>
<tr>
<td>Sonenbum, et al.</td>
<td>Adults</td>
<td>1.7 km</td>
<td>51 min</td>
<td>0.48 m/s</td>
</tr>
<tr>
<td><strong>Summary</strong></td>
<td>--</td>
<td><strong>1.5 – 2.5 km</strong></td>
<td><strong>47-51 min</strong></td>
<td><strong>0.4 – 0.8 m/s</strong></td>
</tr>
</tbody>
</table>

How much people move in wheelchairs is a different question than

How people move in wheelchairs

We are concentrating on the latter
How people move in manual wheelchairs

Distance, time moving & bouts of mobility

• Distance & Time moving are commonly described

• Distance and time are very highly correlated
  – Therefore, do not offer unique information

• Bouts of movement
  – Represent transitions between activities

**START**
- Travel at 0.12 m/s (0.27 mph) for at least 5 seconds
- Traverse at least 0.61 m

**STOP**
- Travel less than 0.76 m over 15 seconds
Design Criteria

• **System**
  – Quick set-up (< 20 minutes)
  – Compatible with all wheelchairs and wheels
    • i.e. rigid & folding frames and spoke & mag wheels
  – Minimize mass to avoid impact on manual wheelchairs

• **Occupancy Switch**
  • sling and rigid seats; different wheelchair cushions
  • different body types, sizes, and sitting postures
  – < 1 cm in height as not to impact seating system or cushion

• **Wheel logger**
  – continuous logging on non-volatile memory for 7+ days without downloading or recharging
  – Acceleration data valid over different surfaces & types of propulsion
Instrumentation to measure wheelchair usage

Occupancy switch with state logger

Wheel-mounted accelerometer & data logger

All instrumentation is commercially available

Analysis code is open sourced
69 Full time manual wheelchair users  
All K0005 wheelchairs  
59,027 bouts of activity  
566 subject-days

### Daily Activity

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td># Bouts</td>
<td>89</td>
<td>83</td>
<td>281</td>
</tr>
<tr>
<td>Distance Wheeled (km)</td>
<td>1.71</td>
<td>1.4</td>
<td>10.5</td>
</tr>
<tr>
<td>Time Spent Wheeling (min)</td>
<td>51.1</td>
<td>45.3</td>
<td>208</td>
</tr>
</tbody>
</table>

### Bout Descriptions

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bout Distance (m)</td>
<td>8.3</td>
<td>0.8</td>
<td>3,891</td>
</tr>
<tr>
<td>Bout Duration (sec)</td>
<td>20</td>
<td>5</td>
<td>2,419</td>
</tr>
<tr>
<td>Bout Speed (m/s)</td>
<td>0.44</td>
<td>0.09</td>
<td>2.65</td>
</tr>
</tbody>
</table>
Other tidbits of manual wheelchair use

• **Long bouts > 5 minutes?**
  – 344 bouts out of 59,151 bouts (<1% bouts)
  – 2/3 of the subjects had at least 1 long bout
  – 15 subjects had > 5 long bouts
    • representing > 80% of bouts longer than 5 minutes

• **Fast bouts > 1 m/s?**
  – 1870 bouts out of 59,151 (3%)
  – Every subject has at least 1 fast bout
  – 41 subjects had at least 10 fast bouts
## Predicting Wheelchair Use

<table>
<thead>
<tr>
<th>Predictor</th>
<th># Bouts</th>
<th>Distance Wheeled</th>
<th>% Mobile</th>
</tr>
</thead>
<tbody>
<tr>
<td># Years in WC</td>
<td>1.705 **</td>
<td>29.98 **</td>
<td>0.121 **</td>
</tr>
<tr>
<td>Gender: Female</td>
<td>5.270 *</td>
<td>n/s</td>
<td>1.0213 **</td>
</tr>
<tr>
<td>Race: Black / African-American</td>
<td>-11.264 **</td>
<td>-264.0 *</td>
<td>n/s</td>
</tr>
<tr>
<td>Education: High School</td>
<td>8.432 **</td>
<td>301.72 **</td>
<td>2.279 **</td>
</tr>
<tr>
<td>Employed or Student</td>
<td>n/s</td>
<td>224.35 **</td>
<td>1.443 **</td>
</tr>
<tr>
<td>Lives Alone</td>
<td>n/s</td>
<td>279.10 **</td>
<td>n/s</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>14.84%</td>
<td>13.46%</td>
<td>13.13%</td>
</tr>
</tbody>
</table>
## Predicting Wheelchair Use

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<th>% Mobile</th>
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<tr>
<td># Years in WC</td>
<td>↑</td>
<td></td>
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<tr>
<td>Gender: Female</td>
<td>↑</td>
<td>n/s</td>
<td>↑</td>
</tr>
<tr>
<td>Race: Black / African – American</td>
<td>↓↓↓</td>
<td>↓</td>
<td></td>
</tr>
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<td></td>
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</tr>
<tr>
<td>Lives Alone</td>
<td>↑</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>14.84%</td>
<td>13.46%</td>
<td>13.13%</td>
</tr>
</tbody>
</table>
Let’s look deeper at 2 people

- Female
- 22 years old
- Cerebral palsy
- Employed
- Independent in transfer
- Cannot stand or ambulate

- Male
- 24 years old
- Spina Bifida
- Employed
- Independent in transfer
- Cannot stand or ambulate
• Same mean daily distance over a week
• 2 km is about **35-40%** of a typical US ambulating adult
• ♂ shows a typical pattern with depressed weekend activity
• ♀ shows less day to day variance (25% vs 50% C.V.)
• Both full time users in wheelchairs for many hours
• ♂ pretty much in chair while awake
• ♀ appears to transfer into and out of chair (*she is employed*)

• ♀ more activity while in chair
• Does ↑ activity rate mean ↑ exertion?
Power Wheelchair Use
### Daily Activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouts per day</td>
<td>110</td>
<td>0</td>
<td>441</td>
</tr>
<tr>
<td>Daily distance</td>
<td>1.1 km</td>
<td>0</td>
<td>13.9 km</td>
</tr>
<tr>
<td>Daily time moving</td>
<td>58 min</td>
<td>0</td>
<td>224 min</td>
</tr>
</tbody>
</table>

Manual was 1.4 km

### Bout Descriptions

<table>
<thead>
<tr>
<th>Description</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bout duration</td>
<td>18 s</td>
<td>5.0 s</td>
<td>66 min</td>
</tr>
<tr>
<td>Bout distance</td>
<td>3.9 m</td>
<td>0.8 m</td>
<td>2900 m</td>
</tr>
<tr>
<td>Bout speed</td>
<td>0.25 m/s</td>
<td>.002 m/s</td>
<td>2.5 m/s</td>
</tr>
</tbody>
</table>

Manual was much faster - 0.44 m/s

25 full-time power users
30,000 bouts of mobility
395 subject days
### POWER WHEELCHAIR USERS

Median bout characteristics differ based on environment.

<table>
<thead>
<tr>
<th></th>
<th>Distance (m)</th>
<th>Duration (sec)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td>3.7</td>
<td>18</td>
<td>0.22</td>
</tr>
<tr>
<td>Not Home Indoors</td>
<td>4.2</td>
<td>18</td>
<td>0.28</td>
</tr>
<tr>
<td>Not Home Outdoors</td>
<td>11.3</td>
<td>34</td>
<td>0.44</td>
</tr>
</tbody>
</table>

In home mobility accounted for:

- 59% of distance
- 64% of time moving
- 75% of bouts

Bouts: transitions between activities
Comparison of walking bouts to wheelchair bouts

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>60% ≤ 30 s</td>
<td>63% ≤ 30 s</td>
<td>70% ≤ 30 sec</td>
</tr>
<tr>
<td>81% ≤ 70 s</td>
<td>85% ≤ 60 s</td>
<td>89% ≤ 60 s</td>
</tr>
</tbody>
</table>

Why should we care?

Research and policy perspectives

• Variation of wheelchair use is great across & within people
  – Complicates ability to represent ‘norms’ parametrically
• Wheelchair users have depressed mobility
  – Construct of ‘mobility disability”
• Short bouts of movement dominate wheelchair usage
  – Wheelchair users move about like ambulators
• Propulsion efficiency: how should we study?
  – self-selected speed or typical everyday speeds?
  – Steady state propulsion or maneuvering?
• Defining ‘dose of wheelchair use’ is not as simple as
  – Using ‘time in wheelchair per day’
  – Using time since injury or time since becoming a wheelchair user
Why should we care?

**Clinical perspective**

- Short bouts of mobility are defined by starting, stopping and turning
  - Maneuvering needs to be a key functional consideration
  - By extension, wheelchair maneuverability is a key prescription consideration
    - maybe top speed should not be our main focus
- Maneuvering throughout the day impacted by the frictional and inertial parameters of the chair
Questions?
Dedicated pressure reliefs and functional in-seat movements as pressure redistributing strategies
More Objectives

- To discuss how in-seat movements impact the buttocks-cushion interface
- To present data about weight shifts and pressure reliefs of wheelchair users in everyday life
- To relate functional movements and in-seat activity to tissue health
Let’s consider groups of PU causation

- **Sustained** violation of load-duration thresholds
  - We do not know this threshold for individuals
    - Individualistic factors are in play
  - *Equipment & equipment fit are often culprits*
    - “Is it the bed or the wheelchair or another chair or all of them?”

- **Episodic** events
  - Bump in transfer
  - Stuck in a poor surface or position
  - Absence of attendant care
  - Equipment problem

- Combination of the two

Evaluation & training are interventions used for both categories
‘sustained overloading’

- Addressed by equipment and training
  - Reduce magnitude of loading
    - Posture & seating system
  - Reduce duration of loading
    - Weight shifting activities
Weight Shifting & Pressure Reliefs

• Guidelines vary
  – 30 second weight shift every 30 minutes
  – 60 sec weight shift every hour
  – 30 sec weight shift every 15 minutes

• The wide range indicates lack of supporting evidence

• No studies have identified pressure reliefs as factors in preventing ulcers
  – Based upon self-report

• Controlled studies suggests >60 secs for perfusion to return
  – Coggrave & Rose 2003

Consortium for Spinal Cord Medicine; PVA 2000
O’Connor & Salcido, in *Spinal Cord Medicine*, 2002
Each of these tasks are equally feasible

- Holding a push-up pressure relief for 60 secs
- Juggling a chain saw, M&M and bottle of beer
- Understanding teenage girls
Weight Shifts and Pressure Reliefs

- Functional constraints limit options for independent weight shifting
- In-seat activity redistributes loading on the buttocks
  - Shifting center of mass alters buttocks loading
Weight Shifts
Study 1: Effect of weight shifting maneuvers

• Hypothesis:
  – Weight-shifts, other than full push-ups, significantly alter ischial pressure and blood flow

• Weight-shifts include
  – Reaching- leaning- and other functional activities

• Approach:
  – measure interface pressure and blood flow during weight shifts
  – Compare cushion’s influence
Effects of wheelchair cushions and pressure relief maneuvers on ischial interface pressure and blood flow

- 6 seated postures
- 3 cushions
- 19 persons with spinal injury

Pressure sensor
Blood flow transducer

7.5 cm
Changes in ischial *pressure* and *bloodflow* compared to upright sitting

<table>
<thead>
<tr>
<th>Position</th>
<th>Decrease in pressure</th>
<th>Increase in Blood flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small frontward lean</td>
<td>-7%</td>
<td>30%</td>
</tr>
<tr>
<td>Intermediate frontward lean</td>
<td>-29%</td>
<td>95%</td>
</tr>
<tr>
<td>Full frontward lean</td>
<td>-80%</td>
<td>320%</td>
</tr>
<tr>
<td>Intermediate sideward lean</td>
<td>-46%</td>
<td>330%</td>
</tr>
<tr>
<td>Full sideward lean</td>
<td>-72%</td>
<td>450%</td>
</tr>
</tbody>
</table>


Positions in red were significantly different from upright posture
Ischial Pressures across cushions

Matrix Vi    Jay2    Roho

Signif higher than others - upright

No diff

No diff
Clinical implications

• Leaning can reduce loading and increase blood flow at the buttocks
  – Only ‘hands-on-knees’ did not have impact

• Interaction between posture and cushion
  – How cushion responds to weight shift differs across cushion

• During full weight shifts- cushions act similarly
Study 2:
Does in-seat movement affect Microclimate: Heat and moisture

• Clear evidence that microclimate is important
  – Especially in populations with poor regulation
• Movement dissipates heat and humidity
Monitoring temperature and humidity over a day

Long bouts of sitting

Temperature (°C)

80% RH

humidity

occupancy switch

Temperature (°C)


Start time: 11/24/2008 10:29:59 AM
Monitoring temperature and humidity over a day

Frequent weight shifting activity
Clinical Implications: Microclimate

• Movement dissipates heat and humidity
  – Put people in a system that permits activity
  – Educate people to move

• **Judicious approach:** if someone commonly sweats on a cushion- *change it*
Study 3 & 4
Monitoring Weight-shifting activities during everyday life

- Research questions:
  - How does in-seat movement differ across wheelchair users?
  - Does pressure ulcer occurrence differ according to the amount of weight-shifting?
- Monitor people with and without a history of pressure ulcers
  - Compare behaviors across groups
- Monitor new wheelchair users over 12 months
  - Compare behaviors of those who develop ulcer and those who do not
  - Sneak peek at the first time period, but still following subjects
Seat monitor and data logger

- 4 force-sensing resisters located under buttocks
- Data-logger captures forces at 1 Hz
- Will present data on 29 persons
  - 18 no PU history
  - 11 with PU history
Raw data is a continuous signal of forces that are run through a classifier.
Definitions

- **Out of Chair** – fully unloaded for > 2 minutes
- **Full Pressure Relief (PR)** – left and right sides fully unloaded for > 15 seconds and < 2 minutes
- **Weight Shift (WS)** – either side or both sides are partially unloaded (<70% upright loading) for > 15 seconds
- **In-seat activity** – movement of seat sensor CoP
How long do full time users sit in their wheelchairs?

This study:

<table>
<thead>
<tr>
<th>Manual WC users</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>10.5 hrs</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Prior studies

<table>
<thead>
<tr>
<th>WC users</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 Manual</td>
<td>10.5 hrs</td>
<td>5.2</td>
</tr>
<tr>
<td>20 Power</td>
<td>10.8 hrs</td>
<td>2.9</td>
</tr>
</tbody>
</table>

For full time users, the wheelchair is not merely a means of conveyance, it is an extension of their functional being.

*Sonenblum, et. al 2008 & 2012*
Many full time wheelchair users transfer a lot

199 days, Median = 8 xfers
Full Pressure Reliefs and Weight Shifts Daily Frequencies per Occupancy-hour

Full Pressure Relief (PR) – left and right sides fully unloaded for > 15 sec & < 1 min

Weight Shift (WS) – either side is partially unloaded (<70% upright loading) for > 15 sec
Maximum Time Between Weight Shifts Daily

![Histogram showing maximum seated time between weight shifts (min) and number of days. The x-axis represents maximum seated time (min) ranging from 0 to 420, and the y-axis represents the number of days, ranging from 0 to 50. The histogram peaks between 0 and 60 minutes, with a steady decrease as time increases.](image-url)
Sneak Preview: Acute SCI Subject Averages

9 subjects Participating in Day Program (9-5)
2 days of a 25 yo male with T8 SCI

COP of in-seat movement, Pressure reliefs, Weight shifts
Two days of a 29 yo male with T5/6 SCI
COP of in-seat movement, **Pressure reliefs, Weight shifts**
Vastly different in-seat movement of 3 persons

COP of in-seat movement

Pressure reliefs

Weight shifts

Subject A

Activity
Weight Shifts
Pressure Reliefs

Activity Freq = 46.3

Subject B

Activity Freq = 82.6

Subject C

Activity Freq = 102.9
Study 5 & 6
Everyday Use and Biomechanical Effects of Power Tilt

For people at high risk, powered tilt and tilt/recline systems are available.
The impact of tilting on blood flow

<table>
<thead>
<tr>
<th>Tilt Position</th>
<th>Increase in Mean Blood Flow Compared with Upright (SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°</td>
<td>8% (19%)</td>
<td>0.016</td>
</tr>
<tr>
<td>30°</td>
<td>24% (48%)</td>
<td>0.003</td>
</tr>
<tr>
<td>45°</td>
<td>84% (84%)</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Challenge lies in getting users to fully engage the functionality

“Pressure Relieving Tilts”
(Tilts > 30° lasting > 1 minute)

Use of tilt feature
(Angle change of 5° lasting > 20 sec)

Use of tilt feature per hour

## Putting It Together

<table>
<thead>
<tr>
<th></th>
<th><strong>Power Tilt</strong></th>
<th><strong>Manual Weight Shifts</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMALL MOVEMENTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle change of</td>
<td>3.0 (2.9)</td>
<td>Weight Shift: Pressure Reduction to &lt; 70%</td>
</tr>
<tr>
<td>5° lasting &gt; 20 sec</td>
<td></td>
<td>2.4 (2.2)</td>
</tr>
</tbody>
</table>
| INTERMEDIATE / LARGE MOVEMENTS | 0.3 (0.5) | Pressure Relief: Complete unloading of both buttocks lasting > 15 seconds | 0.4 (0.5)
Clinical implications

• **Wheelchair users do not demonstrate routine**
  – All were trained in PRs and to target a frequency
  – We cannot assume dedicated PRs are routine

• **Weight shifts are much more common**
  – Our definition required 15 sec duration
  – Intermediate forward and side leans qualify
  – In-seat movement can have an impact so education should address these activities
Interface pressure mapping is useful when teaching pressure reliefs and weight shifts.
In summary

• Weight-shifts are based upon PU models linking time@pressure to necrosis

• Activity is good
  – put people in a position that they can do stuff
  – Seating systems and training to facilitate transfers
  – encourage activity-
    • leaning and reaching has positive tissue benefits
    • Weight shifts impact microclimate

• Most persons do not have a weight shift routine
Acknowledgements

• Stephen Sprigle, PhD, PT
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  – Chris Maurer
  – David Kreutz
• Duke / Durham VA
  – Kevin Caves
  – Helen Hoenig
• Kessler Institute of Rehabilitation
  – Trevor Dyson-Hudson
  – William Weber

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References

Possible Sources for Data Loggers and Switches

- Gulf Coast Data Concepts
  [http://www.gcdataconcepts.com](http://www.gcdataconcepts.com)
- MSR
- ActivPal
- Alimed
  [http://www.alimed.com](http://www.alimed.com)
Questions?