Mobile Health (mHealth) based Physical Activity Intervention System (PAIS) for Individuals with Spinal Cord Injury in the Community

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Disclosures

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Learning Outcomes

At the conclusion of this activity, the participant will be able to:

1. Describe mobile-health based physical activity intervention systems that track physical activity levels.

2. Describe physical activity intervention systems that provide just-in-time adaptive physical activity intervention.

3. Describe typical physical activity patterns of individuals with spinal cord injury in the community.

4. Describe some of the challenges involved with helping individuals to change those patterns.
Outline

• Evaluation of existing activity monitors

• Development of Physical Activity Monitoring System (PAMS)

• Pilot trial of Physical Activity Intervention System (PAIS)
  – A Just-In-Time-Adaptive Intervention system
Introduction

• Healthy People 2020 indicated that 54% of 50 million individuals with disabilities in the US do not perform regular physical Activity (PA)
  - 3.3 million wheelchair users

• Regular PA is crucial in wheelchair users

• Only 20% of persons with spinal cord injury (SCI) reported regular PA

Healthy People 2020; Lai et al. 2017, Ginis et al. 2017
Fernhall et. al. 2008; Tasiemsiki et al. 2005
Introduction

• Wheelchair users can attain recommended physical activity levels
  – Wheelchair basketball, tennis, handcycling
• Self-monitoring of diet, PA and body weight can assist in maintaining a healthy lifestyle
• PA Surveys
  – Human Activity Profile
  – Physical Activity and Disability Survey
  – Physical Activity Scale for Individuals with Physical Disabilities
  – Physical Activity Recall Assessment of People with SCI

Rimmer et al. 2001
Washburn et al. 2002, Ginis et al. 2005
Activity Monitors in Use


https://www.fitbit.com/charge2
Approach

• Assist wheelchair users to attain the recommended PA level by providing them with tools that help quantify their PA

Purpose

– Develop and evaluate a physical activity monitor for wheelchair users
Prior Research

• Kiuchi 2014, Nightingale 2014
  – Wrist accelerometry

• Postma 2005
  – Activity Monitor: five devices worn on body
  – Distinguish propulsion from other activities

• Tolerico 2007
  – Wheel rotation monitor
Evaluation of SenseWear Activity Monitor in Wheelchair Users

- K4b2 metabolic cart
  - O2 inhaled
  - CO2 exhaled

- SenseWear on arm
  - 3-axis accelerometer
  - Skin temperature
  - Galvanic skin response
  - Near body temperature
Results

EE prediction error using manufacturer’s equations for SW

EE measured by K4b2 and SW

<table>
<thead>
<tr>
<th>Trials</th>
<th>K4b2</th>
<th>SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2mph on dyno</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3mph on dyno</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3mph on tile</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>20W at 60 rpm</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>40W at 60 rpm</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>40W at 90 rpm</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Deskwork</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
QDA classifier using four features to detect wheelchair-based activities

<table>
<thead>
<tr>
<th>Class</th>
<th>Rest</th>
<th>Propulsion</th>
<th>Ergometry</th>
<th>Deskwork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td>33</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Propulsion</td>
<td>0</td>
<td>116</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Arm-ergometry</td>
<td>0</td>
<td>9</td>
<td>133</td>
<td>0</td>
</tr>
<tr>
<td>Deskwork</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>32</td>
</tr>
</tbody>
</table>

Overall classification accuracy: 96.3%

Hiremath et al. 2013
Two Step Process

Average% for various trials

- Manufacturer’s model
- General Model
- Activity-Specific Model
SenseWear Activity Monitor in Wheelchair Users

- Machine learning classifiers can detect wheelchair related activities
  - Resting, wheelchair propulsion, arm-ergometry, deskwork
- Activity-specific and general models can be used to estimate energy expenditure
Physical Activity Monitoring System (PAMS)

• Why PAMS?
  – Orphan Market
  – Real-time feedback
  – Meaningful feedback for wheelchair users
  – Modular system

• Purpose
  – Develop and evaluate a new Physical Activity Monitoring System
PAMS

Accelerometer

Wheel monitor

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Wheel Rotation Monitor

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Percentage error for 3 wheel rotation monitors

Error % for distance

Hiremath et al. 2013

Error within ±2%
Testing of PAMS

• 45 manual wheelchair users with SCI
  – Laboratory (N=25)
  – National Veterans Wheelchair Games 2012 (N=20)
  – Home (N=20)

• Activities Performed
  – Resting
  – Arm-Ergometry
  – Darts, Basketball
  – Deskwork, Watching TV
  – Folding Clothes, Laundry
  – Food Preparation, Eating Simulation
  – Propulsion: Carpet, Tile, Ramp, Home
  – Resistance: Band, Dumbbell, Handgrip
  – Making Bed, Floor Sweeping
  – Cleaning Room, Vacuuming
  – Wheelchair Pushups

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Energy expenditure for various activities

Energy expenditure in kcal/min

Energy Expenditure
Mean Acceleration and Distance Travelled

- Activity Trials
  - Resting
  - Arm-Ergometry
  - Darts
  - Deskwork
  - Folding Clothes
  - Carpet
  - Propulsion Moderate
  - Slow
  - Invest Pushing
  - Resistance

- WocketArm
- DistTravelled

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## Predicting Activities using PAMS

<table>
<thead>
<tr>
<th>True\Predict</th>
<th>R</th>
<th>E</th>
<th>NM</th>
<th>Prop</th>
<th>Push</th>
<th>Bask</th>
<th>MM</th>
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</thead>
<tbody>
<tr>
<td>Resting</td>
<td>22</td>
<td>0</td>
<td>24</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Ergometry</td>
<td>0</td>
<td>85</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Activities NM</td>
<td>3</td>
<td>2</td>
<td>135</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Propulsion</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>134</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pushing</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>44</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Basketball</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>27</td>
<td>6</td>
</tr>
<tr>
<td>May move</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>

Hiremath et al. 2014
EE Error for PAMS Estimation

Percentage Error (%)

Resting  Arm-ergometry  OA not moving  Propulsion  Caretaker pushing  Basketball  May be moving  Overall
Discussion

• Regression equations chose demographic characteristics to estimate energy expenditure

• Energy expenditure estimation using PAMS was better than off-the-shelf activity monitors

• Multi-modal information can be utilized to quantify wheelchair-based activities

• Limitations
  – Active population
  – Movement based variables

Hiremath et al. 2016
Pilot Study

- **Aim 1:** Track the baseline physical activity levels
- **Aim 2:** Provide passive feedback about PA levels
- **Aim 3:** Provide just-in-time-adaptive feedback
PAMS

Accelerometer

Wheel monitor

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Community Physical Activity Tracking
Physical Activity Intervention System (PAIS) providing intervention to a participant.
PAIS providing intervention to a participant.
Preliminary Results

- Demographics
  - 13 participants completed (N=20)
  - Age: 42.2 (SD = 13.7) years
  - Years since injury: 13.4 (14.8)
  - 11 male, 2 female
  - 11 paraplegia, 2 tetraplegia
  - Complete injury: 8
Self-Report: Leisure time PA

![Bar chart showing leisure time physical activity (PA) for different participants. The chart details minutes per day spent in light, moderate, and vigorous activity across various participant IDs.]
Self-Report: Pain

Score from 0 to 70

Participant ID

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Self-Report: Fatigue

Score from 7 to 63

Participant ID

1 2 3 4 5 6 7 8 9 10 11 12 13
Physical activity level patterns for an individual with SCI in the community
Conceptual diagram for physical activity at various locations
Physical activity levels performed at different locations or during transit on a single day (Day 5) for the same participant.
Energy expenditure (EE) per day compared with baselines of 11 participants who completed the pilot study.
Low PA levels per day compared with baselines of 11 participants who completed the pilot study.
Moderate PA levels per day compared with baselines of 11 participants who completed the pilot study.
Discussion

• m-Health-based PAIS can be used in conjunction with clinician recommendations to provide community-based interventions for individuals with disability

• While the EE remained similar for nine of the eleven participants, the low and moderate PA levels can be increased by feedback and JITAI conditions

• Three groups emerged from the feedback and JITAI conditions
  – Increase in low and moderate PA levels
  – Increase in low PA levels only
  – Increase in moderate PA levels only
Discussion

• Interviews indicated that inclement weather and pain led to a decrease in moderate PA levels for some of the participants

• Our pilot has highlighted some challenges of conducting work with multiple, real-time sensors:
  – Android wireless connectivity (lack of) robustness
  – Real-time classification and PA level estimation based on the smartphone receiving device data
Conclusion

• To our knowledge, this is the first study to test a PA intervention system that can monitor PA levels and provide both passive feedback and adaptive intervention to individuals with SCI in the community.

• Results of this pilot study indicate that a PAIS has a potential to improve the PA levels of individuals with SCI.
Acknowledgements

• Participants

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  – Marlyn Ramos Lamboy, Moss Rehab Hospital
  – Dan Ding, University of Pittsburgh
  – Rory Cooper, University of Pittsburgh
  – Michael Boninger, University of Pittsburgh
Take Home Message

• Evaluate your technology tools thoroughly
• mHealth research is exciting
• (but very challenging)
• Build multi-disciplinary collaborations
Future Work

• Models that capture behaviors specific to individuals and integrate personalized behavior interventions

• Feedback customized to enhance user interaction and experience with technology

• Community based studies that promote physical activity adherence and reduce secondary conditions (e.g. pain)
Our vision is to understand...
Thank you

- Shiv Hiremath: Shiv.Hiremath@Temple.edu

- PHIRE Lab Website: https://sites.temple.edu/phire/
CE/CME Credit

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https://pva.cds.pesgce.com
Additional Slides
Variation in Mobility

Figure 1: A person-specific function will influence the choice of assistive technology for various mobility modes.

Amiri et al. 2017
Sensor Placement

Figure 2: An investigator using various types of mobility aids. Red circles highlight the SenseWear armbands
Figure 3: A framework consisting of measuring and predicting physical activity and health and function.

1st Level Classification: Mobility vs. Other physical activities