Validating and Testing Wearable Sensors to Assess Physical Activity and Sedentary Behavior in the Center for Personalized Health Monitoring

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Validating and Testing Wearable Sensors to Assess Physical Activity and Sedentary Behavior in the Center for Personalized Health Monitoring

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Department of Kinesiology
School of Public Health and Health Sciences
University of Massachusetts Amherst

May 20, 2014
Outline

- Introduction
- Validation of wearable sensors
- Testing of wearable consumer activity trackers
- Capability of sensor evaluation in Human Testing Center in Center for Personalized Health Monitoring (CPHM)
Human testing facilities in the Center for Personalized Health Monitoring

- Research on wearable monitors to develop algorithms to translate sensor signals into meaningful and biologically valid output for clinical applications
  - Establishing meaning to personal biomarkers of health

- To determine the functionality and wearability of sensors

- Evaluation to determine how human movement affects brain, muscle, bone, tendons, ligaments and supporting structures and systems

- Translation: Evaluation of sensors for the commercial pipeline by establishing accuracy, effectiveness and usability of sensors
  - Usefulness of the ‘Quantified Self’
Relationship between Actigraph counts and METS

![Graph showing the relationship between Actigraph counts and METS.](image)

- $r^2 = 0.82$
- $\text{SEE} = 1.12 \text{ METs}$
- $N = 50$

<table>
<thead>
<tr>
<th>Activity Intensity</th>
<th>MET Range</th>
<th>Activity Counts (cts·min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>$&lt;3.00$</td>
<td>$&lt;1952$</td>
</tr>
<tr>
<td>Moderate</td>
<td>3.00–5.99</td>
<td>1952–5724</td>
</tr>
<tr>
<td>Hard</td>
<td>6.00–9.99</td>
<td>5725–9498</td>
</tr>
<tr>
<td>Very hard</td>
<td>$&gt;8.99$</td>
<td>$&gt;9498$</td>
</tr>
</tbody>
</table>

Freedson et al., MSSE, 1998
Activity counts and cutpoints

Counts

0 10000

Vigorous

Moderate

Clock time

8:24 10:48 13:12 15:36 18:00 20:24 22:48
Minutes of moderate to vigorous physical activity: NHANES 2003-2004
Traditional Data Processing of Accelerometer Data

- Provide physiological meaning to accelerometer data

- Linear regression models
  - Predict point estimate of energy expenditure
  - Classify activity intensity

- Extensively used in the literature to characterize/quantify physical activity behavior

- Numerous revised regression models
  - Confusion in the literature

- Method fails to discriminate intensity levels properly
  - Similar counts with different energy expenditure
    - Walking uphill vs walking on level ground
  - Different counts with same energy expenditure
These three time series of simulated accelerometer data have the same total or mean counts per minute. They would all be classified as “moderate” activity using typical data processing methods, but they could represent activities with substantially different energy costs.
How Can We Maximize the Information Collected?

- Use entire sequence and pattern of accelerometer signal
  - Use features of signal
  - Process with pattern recognition algorithms

- Continual ‘learning’ by example
  - Powerful
  - Flexible
Advanced Data Processing: Machine Learning

Artificial Neural Network

Random Forest

tree \( t_1 \)

\( \sum_{i=1}^{T} t_i(v) > t_n \)

\( P_i(e) \)

\( P_{T}(c) = \sum_{i=1}^{T} P_i(c|v) \)

Support Vector Machine

Support vectors
We tested the method on data from Crouter et al. (2006).

48 subjects did a variety of activities.

Indirect calorimetry used to estimate average PAEE for each person & activity.

Leave 1 out cross validation: method never fit and evaluated on same subject’s data.

Staudenmayer et al, JAP, 2009
Artificial neural network trained to estimate METs and applied to independent dataset

Fig. 1. Measured metabolic equivalents (METs) vs. METs predicted from neural network (nnetMET). The nnetMET was developed on University of Massachusetts (UMass) data set (n = 277) and applied to University of Tennessee (n = 65) data set. The bias was 0.32 METs, and the root mean square error (RMSE) was 1.90 METs.

Freedson et al, JAP, 2011
Machine learning models to detect activity types developed and tested in lab and free living settings in older adults

Sasaki, et al, In Preparation
Consumer wearable sensors to estimate activity and sleep

- Fitbit One
- Samsung Gear Fit
- Fitbit flex
- Garmin Vivofit
- Nike Fuel
- Jawbone Up
- Misfit Shine
- Basis Carbon Steel
- Polar Loop
- Withings Pulse

Consumer wearable sensors to estimate activity and sleep.
Accuracy of the Fitbit in estimating energy expenditure

Methods

- N = 20 college-age participants
- Performed treadmill walking and running and other activities
- Compared ee from indirect calorimetry to fitbit estimate of ee

Fitbit EE vs Indirect calorimetry

Sasaki et al., JPAH, ahead of print, 2014
Compete or share with friends
Up for a little healthy competition? Bring friends and family in on the fun so you can compare stats, share progress, and cheer each other on. Your leaderboard refreshes all day long in the Fitbit App so you know exactly how many more steps you need to rise to the top.
Fitbit output wirelessly transmitted to smart phone or computer: sleep and activity data

- Calories Burned
- Steps
- Active score

Today's activity breakdown (excluding sleep):
- Sedentary: 13hrs 56min
- Lightly active: 1hr 19min
- Fairly active: 1hr 32min
- Very active: 1hr 13min
How does this relate to the CPHM?

- This work uses off the shelf activity sensors
- We have established ourselves as leaders in the activity monitor testing and algorithm development space
- Most of our previous work is in lab settings
- In CPHM we will have the capacity to:
  - Test many types of sensors built in house collaborating with electrical and computer engineering, polymer science, computer science, mathematics and statistics, other disciplines
  - Work with industry (e.g. medical device companies, activity monitor companies)
  - Test in real world instrumented home setting
  - Study clinical applications
    - Use in interventions for self monitoring
    - Social media for motivation and sustaining behavior change
Human testing facilities in CPHM
Human testing facilities in CPHM
Human testing facilities in CPHM
Human testing facilities in CPHM
Normalized overlaid plot for a representative participant (10-year-old boy, weight = 76.5 kg, height = 155 cm) obtained during first 600 min of the ~24-h stay in the whole-room indirect calorimeter.

AHA Scientific Statement

Guide to the Assessment of Physical Activity: Clinical and Research Applications
A Scientific Statement From the American Heart Association

Scott J. Strath, PhD, Chair; Leonard A. Kaminsky, PhD, Co-Chair;
Barbara E. Ainsworth, PhD, MPH, FAHA; Ulf Ekelund, PhD; Patty S. Freedson, PhD;
Rebecca A. Gary, RN, PhD; Caroline R. Richardson, MD; Derek T. Smith, PhD;
Ann M. Swartz, PhD; on behalf of the American Heart Association Physical
Activity Committee of the Council on Lifestyle and Cardiometabolic Health and Cardiovascular,
Exercise, Cardiac Rehabilitation and Prevention Committee of the Council on Clinical Cardiology, and
Council on Cardiovascular and Stroke Nursing
### Decision matrix guide to selecting a physical activity measurement instrument


#### I Want to Measure Physical Activity in my Patients / Participants

<table>
<thead>
<tr>
<th>Step</th>
<th>What is your primary outcome variable of interest?</th>
<th>Tools Available:</th>
<th>Considerations of Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Domain Specific?</td>
<td>1,2</td>
<td>1,2,3,5,6,7</td>
</tr>
<tr>
<td></td>
<td>Walking behavior?</td>
<td>1,2,4</td>
<td>1,2,3,5,6,7</td>
</tr>
<tr>
<td></td>
<td>Meeting PA guidelines?</td>
<td>1,2,3,5,6</td>
<td>1,2,3,5,6,7</td>
</tr>
<tr>
<td></td>
<td>Kcal expended?</td>
<td>1,2,7</td>
<td>1,2,3,5,6,7</td>
</tr>
<tr>
<td></td>
<td>Total PA?</td>
<td>1,2,3,5,6,7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>What do you want to describe?</td>
<td>Intensity?</td>
<td>1,2,3,5,6</td>
</tr>
<tr>
<td></td>
<td>Duration?</td>
<td>1,2,3,5,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frequency?</td>
<td>1,2,3,5,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total PA?</td>
<td>1,2,3,5,6,7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy Expenditure?</td>
<td>1,2,3,5,6,7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>How many people do you want to measure?</td>
<td>Small number?</td>
<td>1,2,3,5,6</td>
</tr>
<tr>
<td></td>
<td>Moderate number?</td>
<td>1,2,3,5,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High number?</td>
<td>1,2,3,5,6,7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>What are the cost considerations?</td>
<td>Relatively inexpensive?</td>
<td>1,2,4</td>
</tr>
<tr>
<td></td>
<td>Moderately expensive?</td>
<td>3,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relatively expensive?</td>
<td>6,7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Patient / participant level of burden?</td>
<td>Has to be low</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Can be moderate</td>
<td>4,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be high</td>
<td>2,3,5,6,7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Personnel available?</td>
<td>Low</td>
<td>1,4</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>5,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>2,3,5,7</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Data processing, data transfer, data summarization?</td>
<td>Has to be Fast/Easy?</td>
<td>1,4</td>
</tr>
<tr>
<td></td>
<td>Moderately Fast/Easy?</td>
<td>2,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Detailed &amp; Time Intensive?</td>
<td>3,6,7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Assessment time considerations?</td>
<td>Fast, Single time point</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Fast to use over a few days</td>
<td>2,3,4,5,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not limited by time</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Immediate feedback for the patient/participant needed?</td>
<td>No</td>
<td>1,2,3,5,6,7</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Method Suggestions:**

Note: 1=Physical activity questionnaires; 2=Physical activity logs/diaries; 3=Heart Rate Monitoring; 4=Pedometers; 5=Accelerometer; 6=Multi-unit Sensors; 7=Doubly Labeled Water
# Acknowledgements

## Collaborators

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>John Staudenmayer</td>
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<tr>
<td>David Pober</td>
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<td>Scott Crouter</td>
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<tr>
<td>David Bassett</td>
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<tr>
<td>Amanda Hickey</td>
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<tr>
<td>Dinesh John</td>
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<tr>
<td>Sarah Kozey</td>
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<tr>
<td>Kate Lyden</td>
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<tr>
<td>Albert Mendoza</td>
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<td>Jeffer Sasaki</td>
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## Funding Support

<table>
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<td>NIH RC1 HL0099557</td>
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Thank-you