Using Mobile Phones for Measurement of Physical Activity and Health Behaviors

Stephen Intille, Ph.D.

Associate Professor
College of Computer and Information Science &
Bouvé College of Health Sciences
Northeastern University (450 WVH)

s.intille@neu.edu

Thanks to...

- **Terrific students and staff**: Dr. Fahd Albinali, Selene Mota, Jason Nawyn, Tony Lazenka, Raj Joshi, Yi Han, Noah MacNeil, Ned Burns, Emmanuel Munguia Tapia, Pallavi Kaushik, Jennifer Beaudin
- **Creative collaborators**: Dr. Bill Haskell (Stanford), Mary Rosenberger (Stanford), Dr. Matthew Goodwin (MIT/Groden Center), Kent Larson (MIT), Ben Kuris (Shimmer), Dr. Laura Svetkey (Duke), Dr. Genevieve Dunton (USC)
- **Generous funders**: **NIH Genes and Environment Initiative**, NSF, Intel, Microsoft, RWJF, Elisa, IBM, House_n Consortium

Take away #1

- Mobile phones are increasingly capable of sophisticated, real-time information processing using internal and wirelessly-connected sensors

- Most people will have this technology and carry it with them nearly everywhere

  (See Pew Internet & American Life (http://www.pewinternet.org/)

Take away #2

- Phones + sensors can detect enough information about behavior to create new methods to facilitate context-sensitive self report (CS-EMA)
- No sensor is perfect: multi-sensor behavior recognition in combination with real-time or interactive time self-report is the path forward

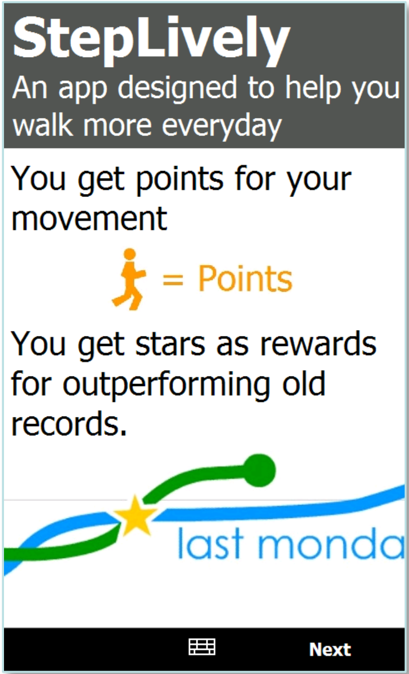
Take away #3

- Work in progress: There are some design and technical challenges, but they can be overcome with more research

Just-in-time intervention

Goals

- Continuous behavior measurement on consumer tech (especially phones) using sensors
- Instant, carefully-timed, tailored feedback for new interventions

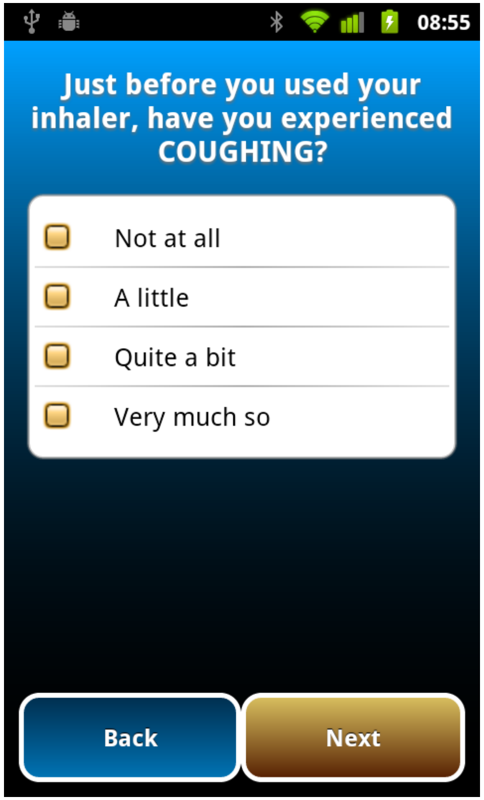


... but will change measurement too ...

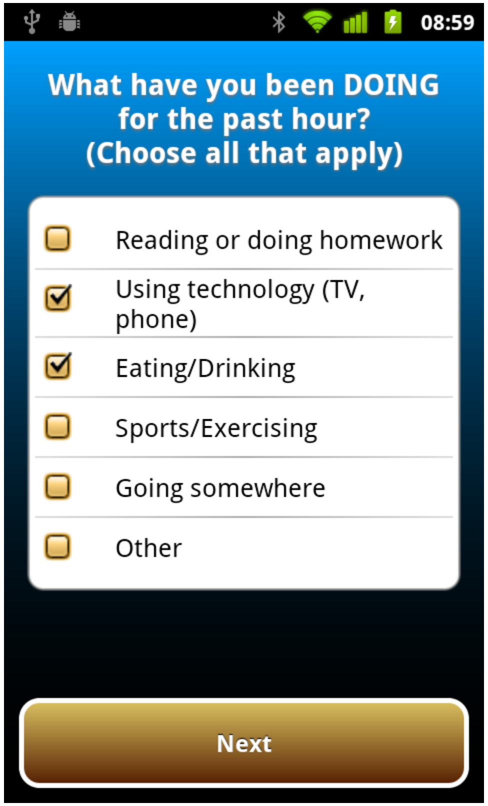
Just-in-time self report

Context-sensitive ecological momentary assessment (CS-EMA)

Prompted just after inhaler used:



Prompted after 60 min of no phone motion:



Teen asthma measurement with Genevieve Dunton at USC

CS-EMA & ubiquitous sensing

- CS-EMA might use a variety of passive sensors (think of “sensor” broadly)
  - In phone
  - Communicating with phone
  - In environment

- Passive sensor processing triggers active self-report to fill in gaps and context

Why CS-EMA?

- Minimize participant burden by targeting requests for context information
- "Fix" problems with imperfect passive sensing (or fill in gaps)
- Get at the "why" of behavior for intervention development

Behavior measurement

Today

- Surveys
- Proprietary objective sensors
- Limited information about context
- 1-7 days of data
- Costly compensation
- Expert-assisted recall for detailed timeline
- Limited location info
- Limited info on decision-making

Soon

- Open source phone apps (with optional add-on sensors)
- Months of continuous data
- Citizen scientists donating info
- Computer-assisted recall (using passive data collection)
- Full location information
- Context/purpose info...

Behavior measurement

Today

- Hypothesis driven investigations to understand correlations

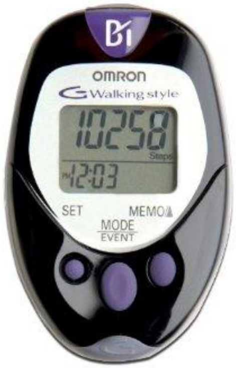
Soon

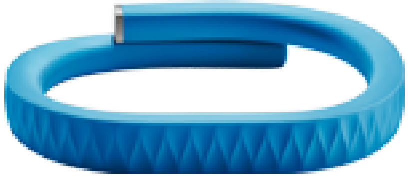
- Data driven, incremental and interactive discovery for intervention theory development

Want to measure behavior?

- With a rich understanding of behavior + context
- In the field
- Long-term (weeks or months+)
- At reasonable cost
- With real-time feedback

Activity monitors abound





Prototype: Wockets system

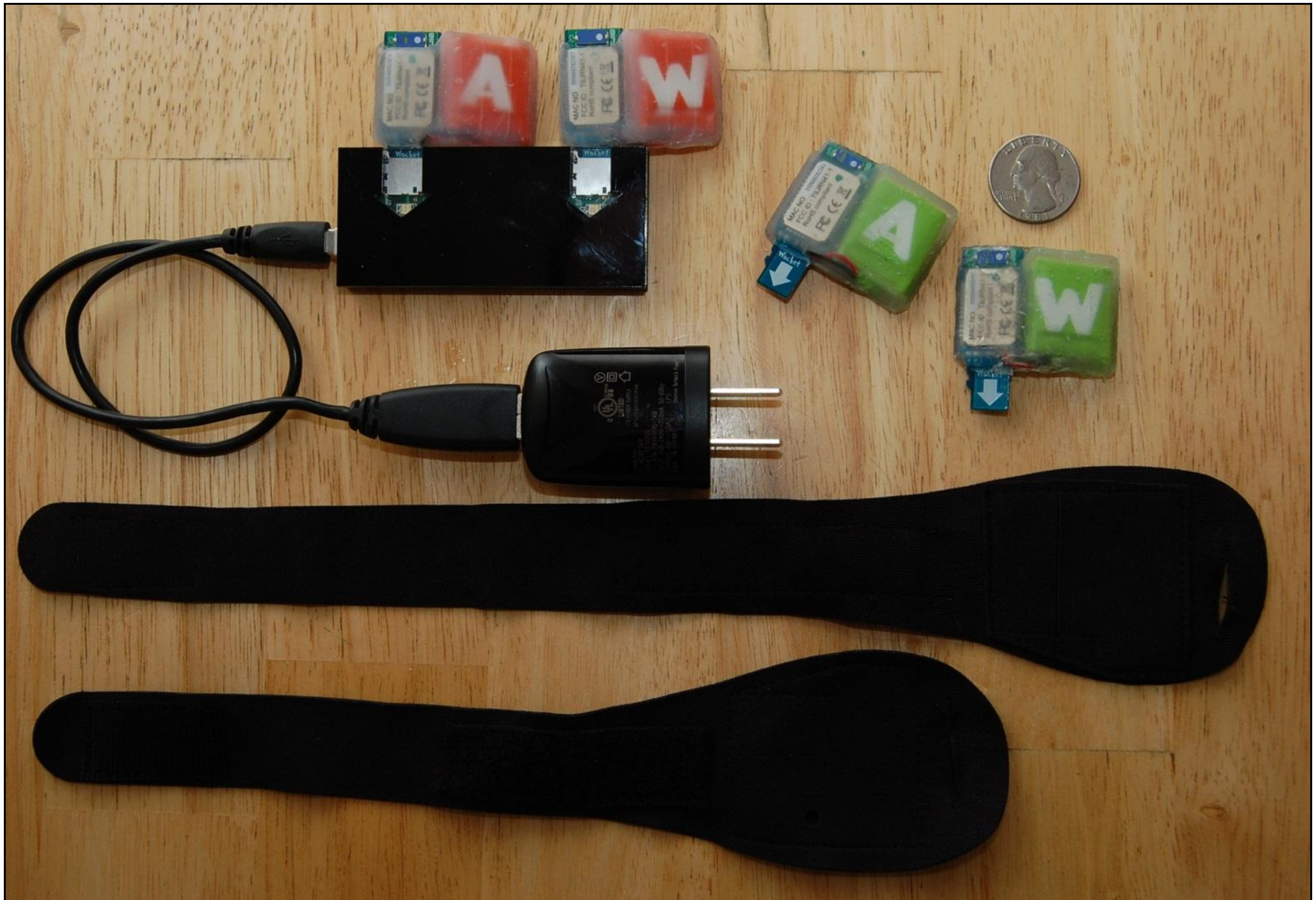
- Goal
  - 24/7 measurement of physical activity of
    - Type
    - Intensity
    - Duration
    - Location
  - For months+ (with compliance feedback)
  - Cost suitable for cohort studies
    - Exploit consumer phone technologies
    - All open source

Wockets system fills a niche

- 24/7 remote data collection that may improve PA/SB research
  - Missing data
    - Real-time compliance feedback
    - Remote compliance monitoring
    - Less reliance on single body location
  - Sampling bias
  - Activity type info via pattern recognition with upper/lower body sensing
  - Combine passive monitor and trigger self-report to fill in context

Wocket "kit" (+ phone)

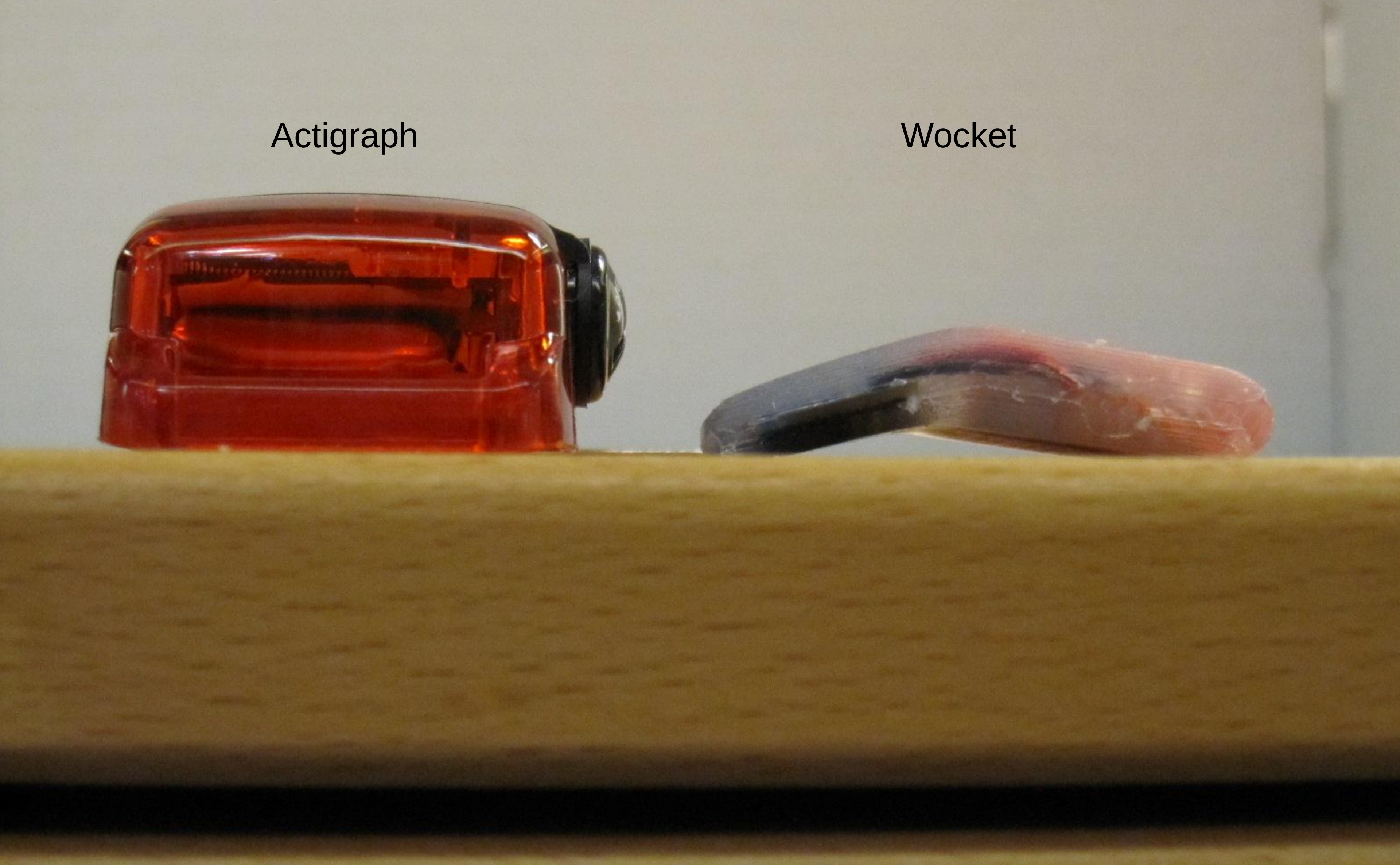
Charge 2



Wear 2 for 24h

Capture upper + lower body motion at 40Hz that can be processed for activity type and intensity detection

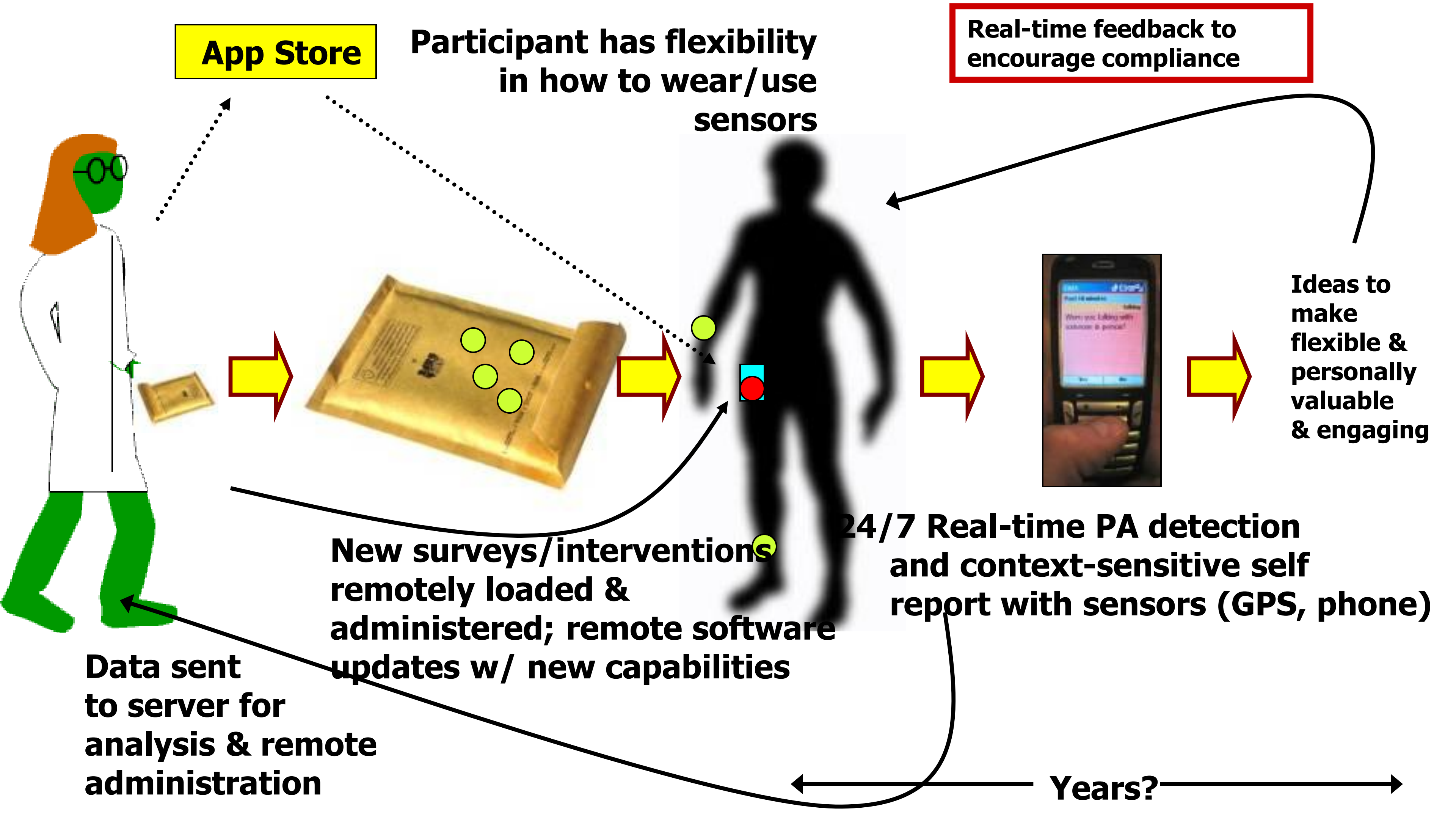
Thin for continuous wearability

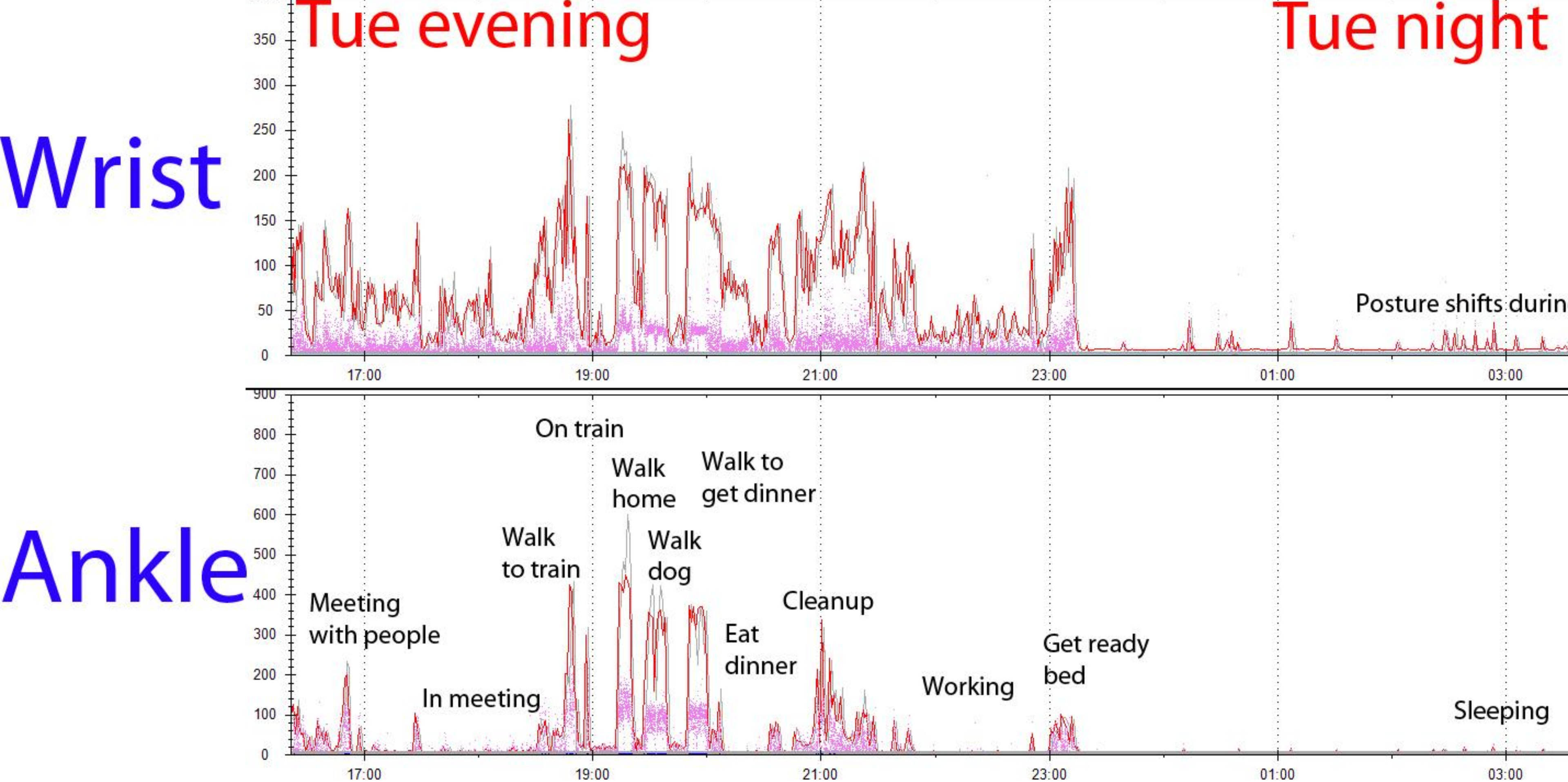


A day in the life of a participant

- In the morning, swap & select locations
  - Usually one upper body, one lower body
  - Internal phone sensors
- During the day – use phone normally
- At night, plug in phone next to bed
- Data transmitted to lab for remote monitoring and incremental analysis

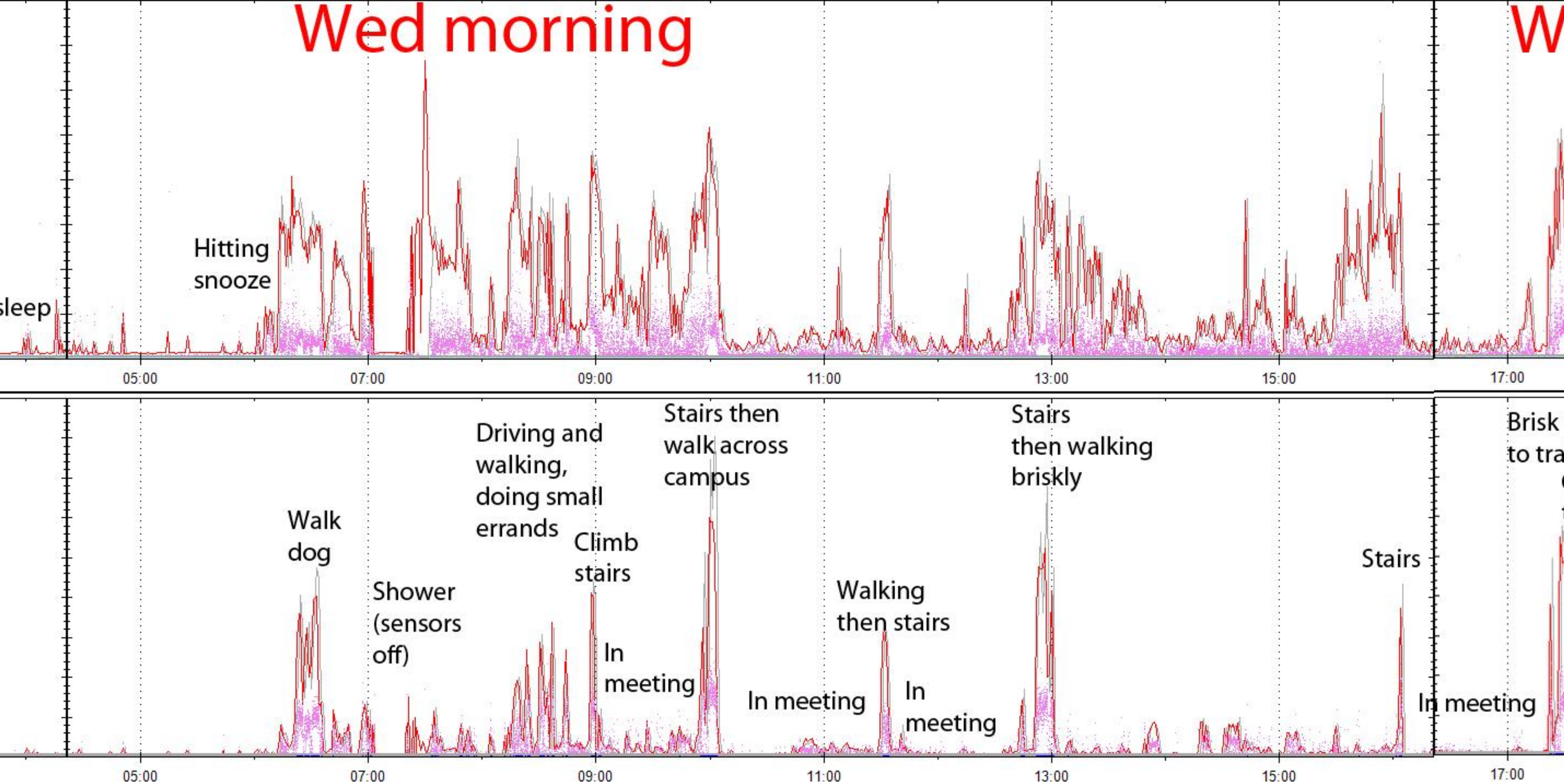
Vision: population-scale

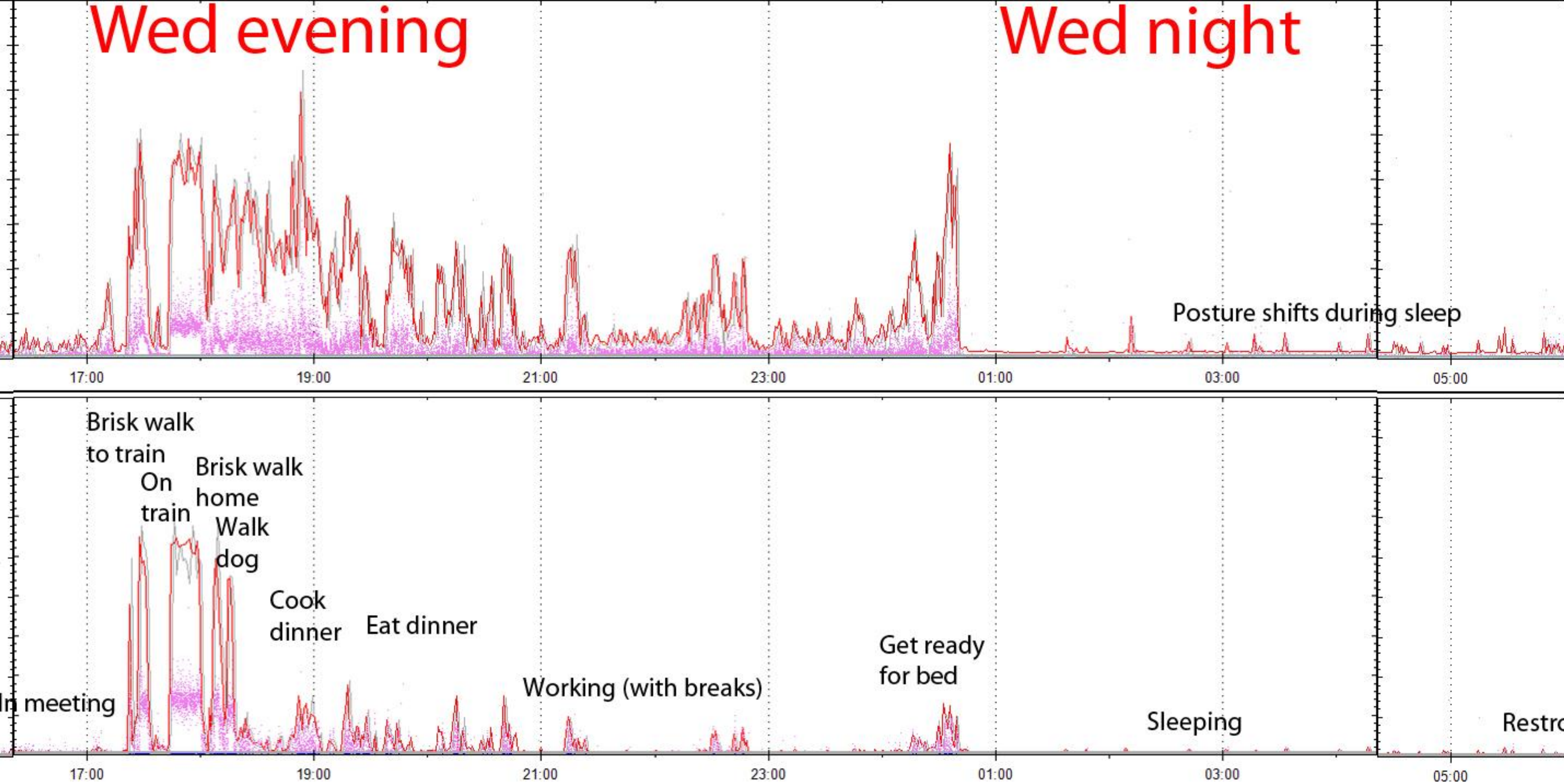


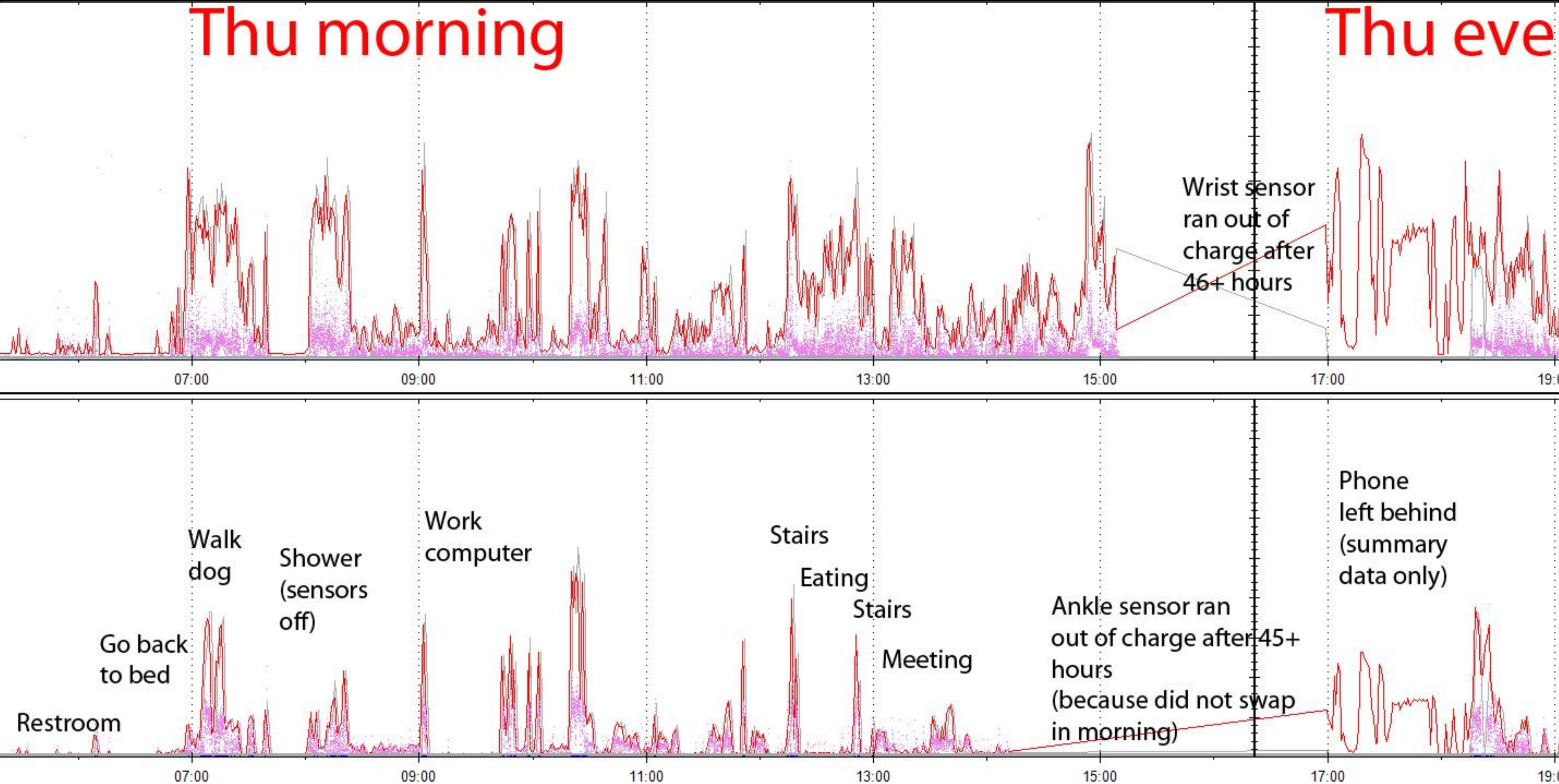


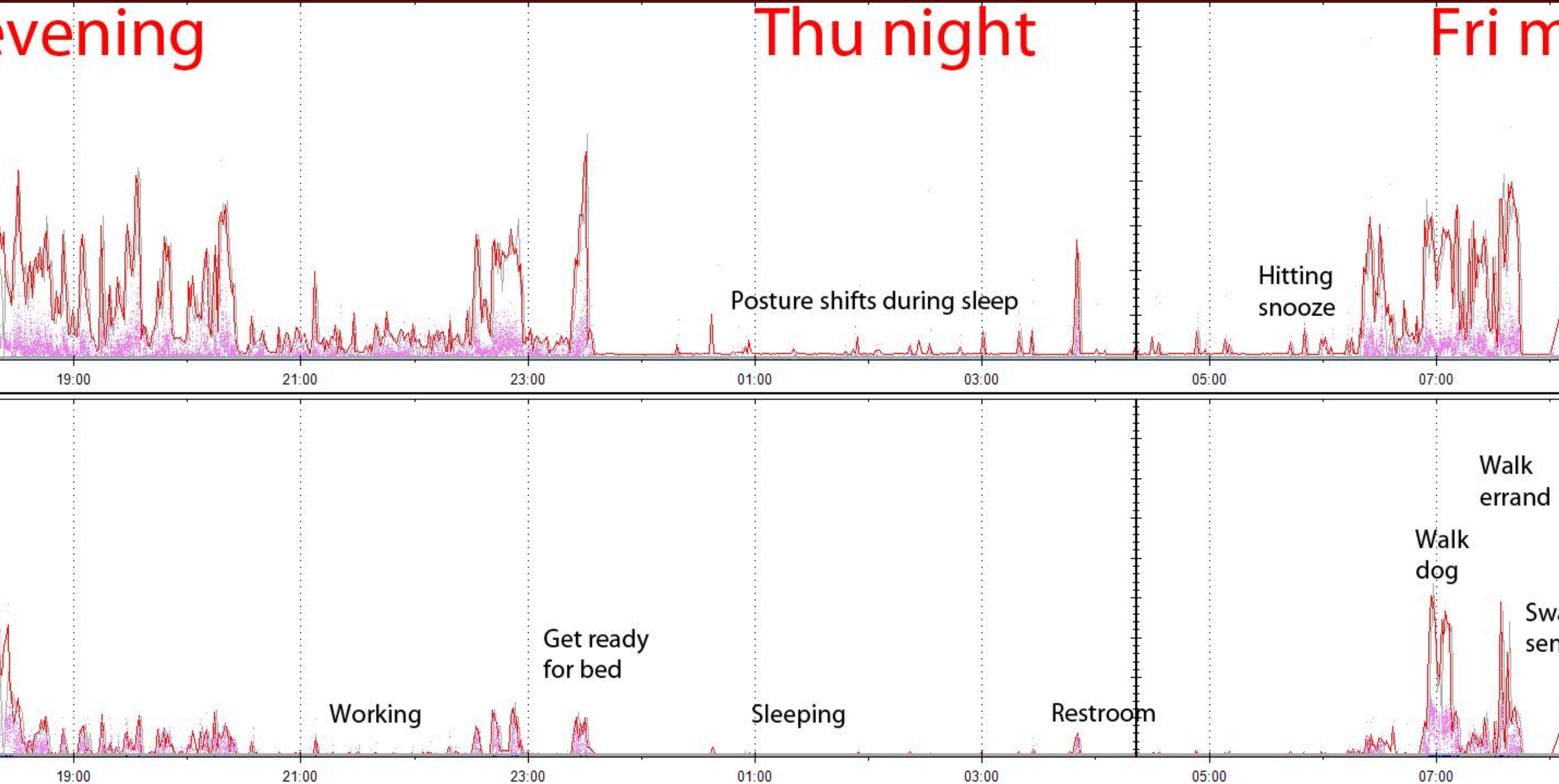
Note: Activities manually labeled ...

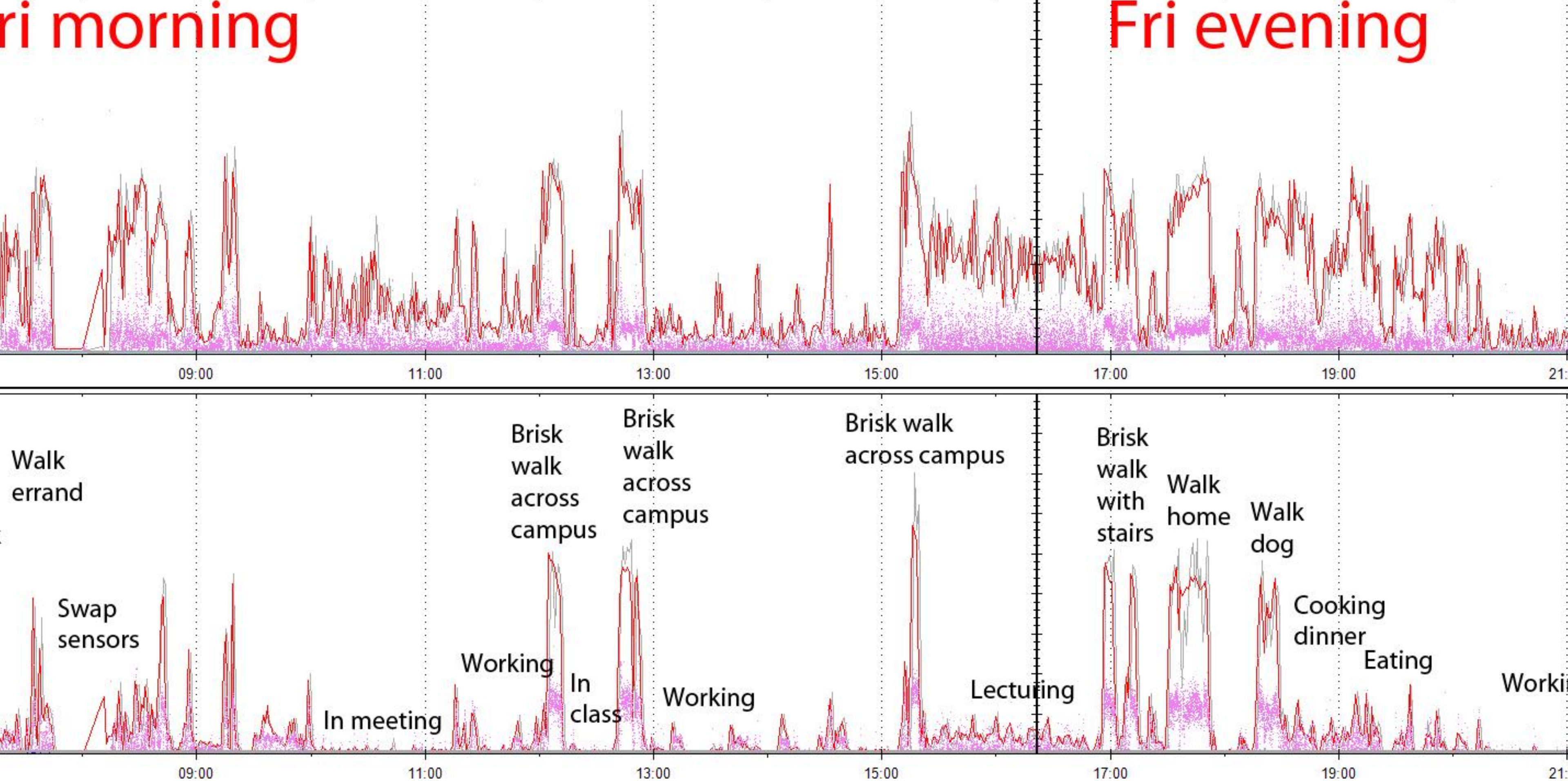
Working on real-time detection of some activity types and context (posture, ambulation, structure exercise, etc.)

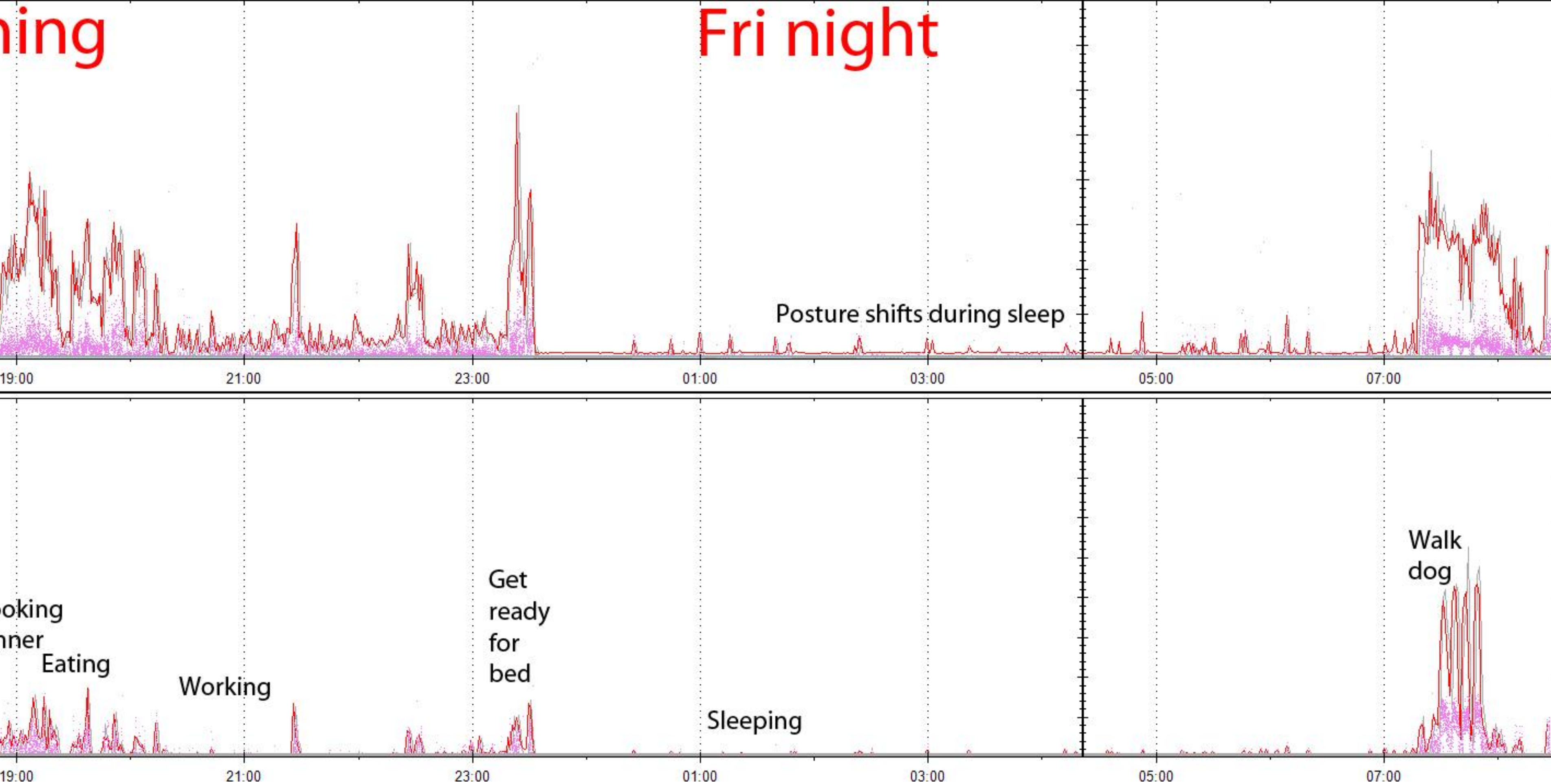

Wed morning
W
sleep
Hitting snooze
05:00
07:00
09:00
11:00
13:00
15:00
17:00
Walk dog
Shower (sensors off)
Driving and walking, doing small errands
Climb stairs
In meeting
Stairs then walk across campus
In meeting
Walking then stairs
In meeting
Stairs then walking briskly
Stairs
In meeting
Brisk
to tra
05:00
07:00
09:00
11:00
13:00
15:00
17:00


Wed evening
Wed night
Posture shifts during sleep
17:00
19:00
21:00
23:00
01:00
03:00
05:00
Brisk walk to train
On train
Brisk walk home
Walk dog
Cook dinner
Eat dinner
In meeting
Working (with breaks)
Get ready for bed
Sleeping
Restro
17:00
19:00
21:00
23:00
01:00
03:00
05:00


Thu morning
Thu eve
Wrist sensor ran out of charge after 46+ hours
07:00
09:00
11:00
13:00
15:00
17:00
Restroom
Go back to bed
Walk dog
Shower (sensors off)
Work computer
Stairs
Eating
Stairs
Meeting
Ankle sensor ran out of charge after 45+ hours (because did not swap in morning)
Phone left behind (summary data only)

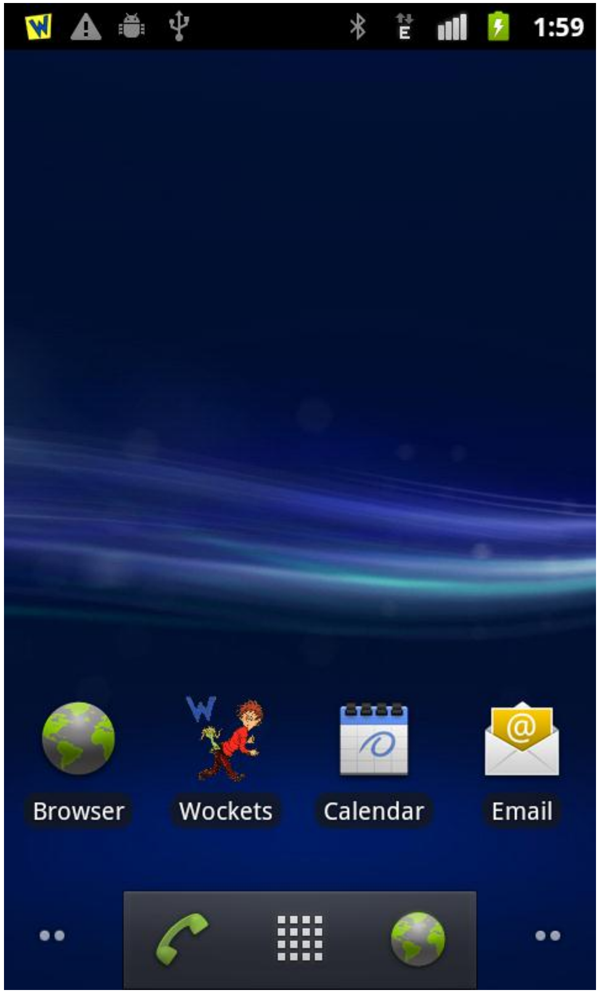

evening
Thu night
Fri m
Posture shifts during sleep
Hitting snooze
19:00
21:00
23:00
01:00
03:00
05:00
07:00
Working
Get ready for bed
Sleeping
Restroom
Walk dog
Walk errand
19:00
21:00
23:00
01:00
03:00
05:00
07:00

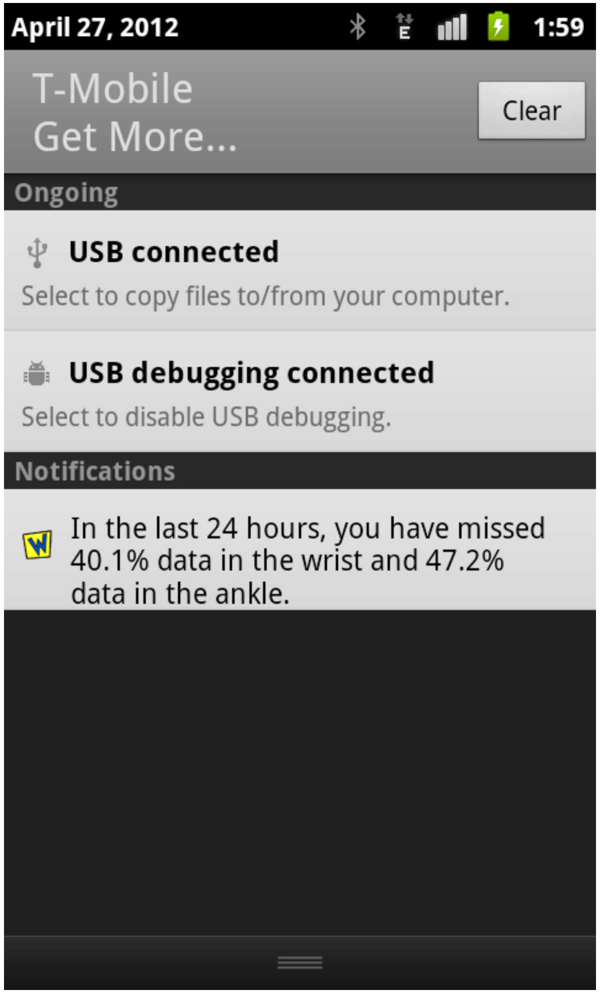

ri morning
Fri evening
09:00
11:00
13:00
15:00
17:00
19:00
21:
Walk
errand
Swap
sensors
In meeting
Working
Brisk
walk
across
campus
In
class
Brisk
walk
across
campus
Working
Brisk walk
across campus
Lecturing
Brisk
walk
with
stairs
Walk
home
Walk
dog
Cooking
dinner
Eating
Worki



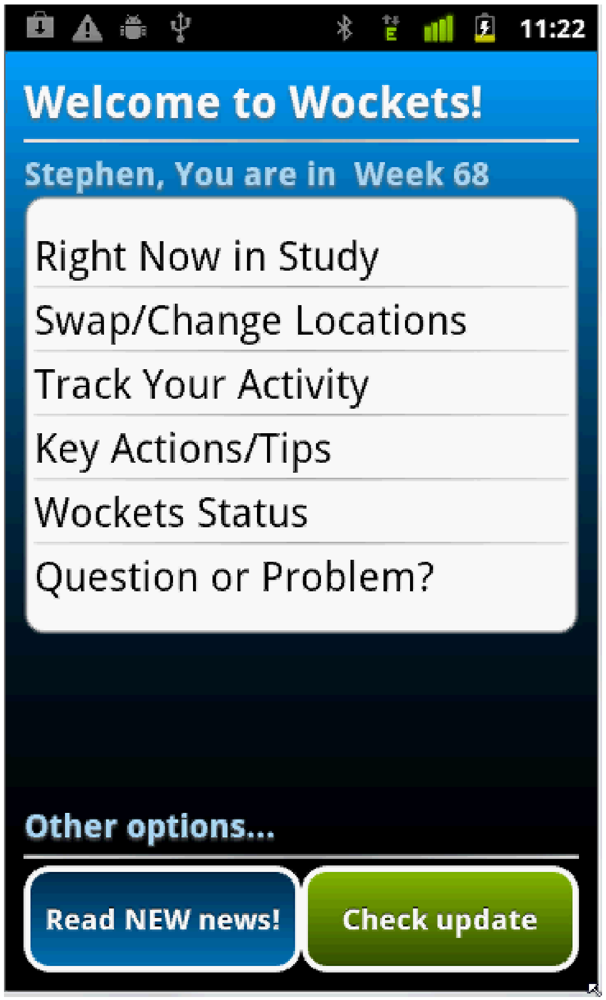
ning
Fri night
Posture shifts during sleep
19:00
21:00
23:00
01:00
03:00
05:00
07:00
oking
nner
Eating
Working
Get
ready
for
bed
Sleeping
Walk
dog
19:00
21:00
23:00
01:00
03:00
05:00
07:00

Compliance feedback





Wockets self-report



Wockets Data Viewer

Convert | Select

Home | Study > | Actions > | Advanced > | Logout

You are viewing data for Thursday 21st of July 2011

Participants:

Intille, Stephen

«			July 2011				»
wk	S	M	T	W	T	F	S
26	26	27	28	29	30	01	02
27	03	04	05	06	07	08	09
28	10	11	12	13	14	15	16
29	17	18	19	20	21	22	23
30	24	25	26	27	28	29	30
31	31	01	02	03	04	05	06

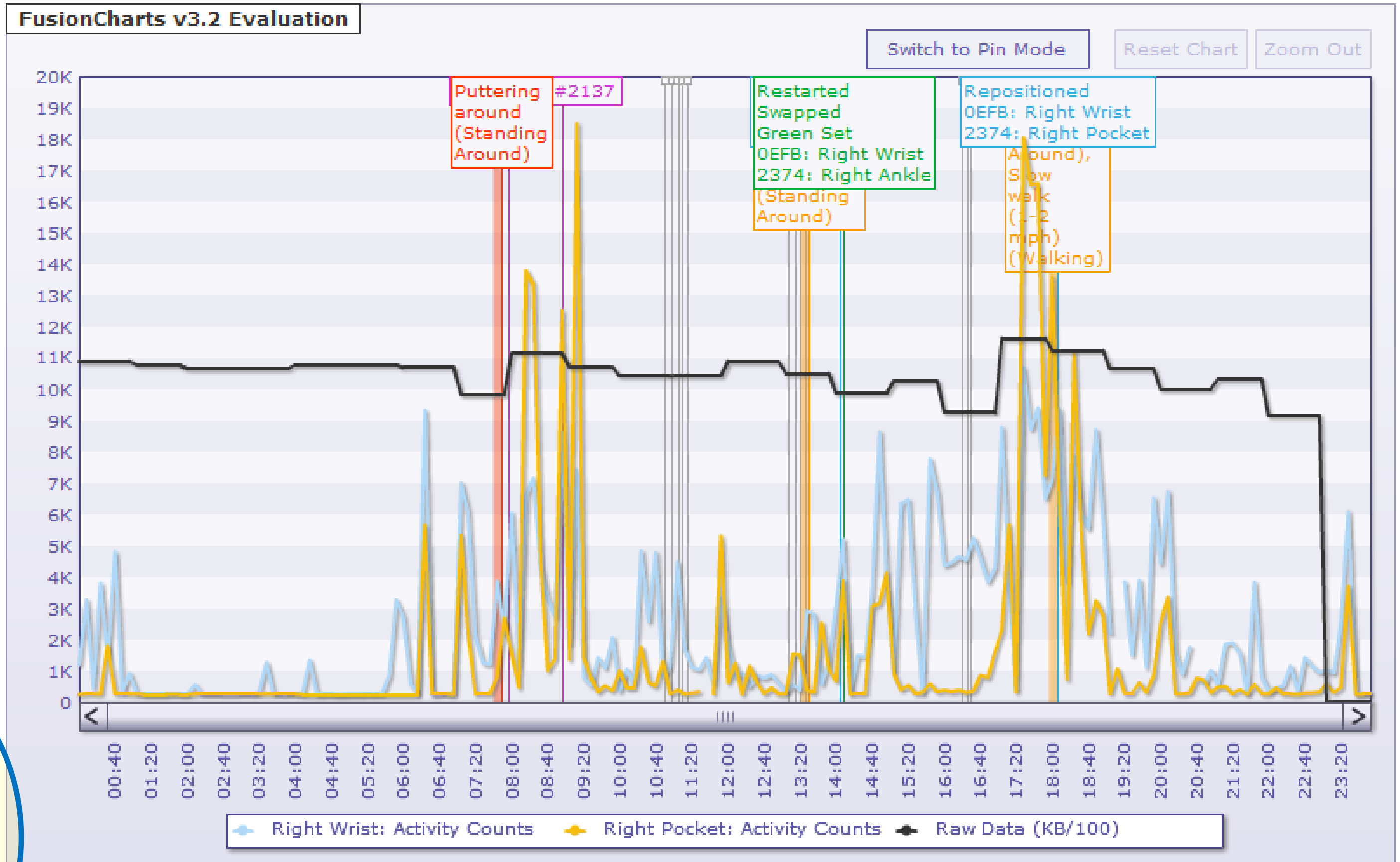
View By:

- (●) Placement
- ( ) MAC Address

Show Options:

- [x] Raw Data
- [ ] Bytes Sent
- [ ] Bytes Received
- [ ] Battery
- [ ] Phone Stats

Apply Settings



SMS #2131

On Wednesday we recorded 99.7% of the data from your wrist sensor and 99.2% of the data from your ankle sensor.

SMS #2137

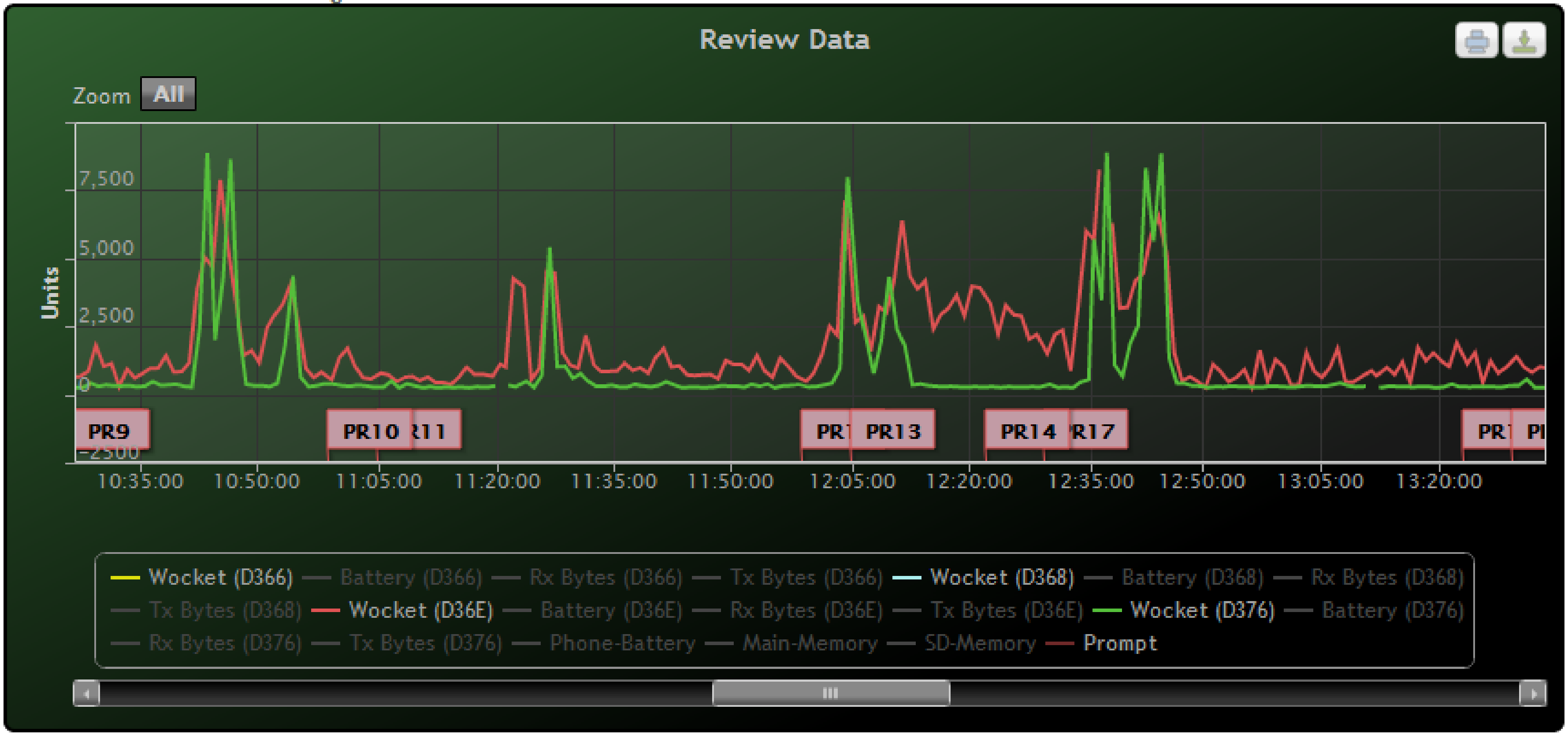
On Wednesday according to your ankle sensor: Sedentary 18 hours, Light activity 4 hours, Physically active 113 minutes.

ew Participant

Study Graph

Participant Id: 6810 Date: 2012-02-27

☑ Enable Y-axis auto scaling



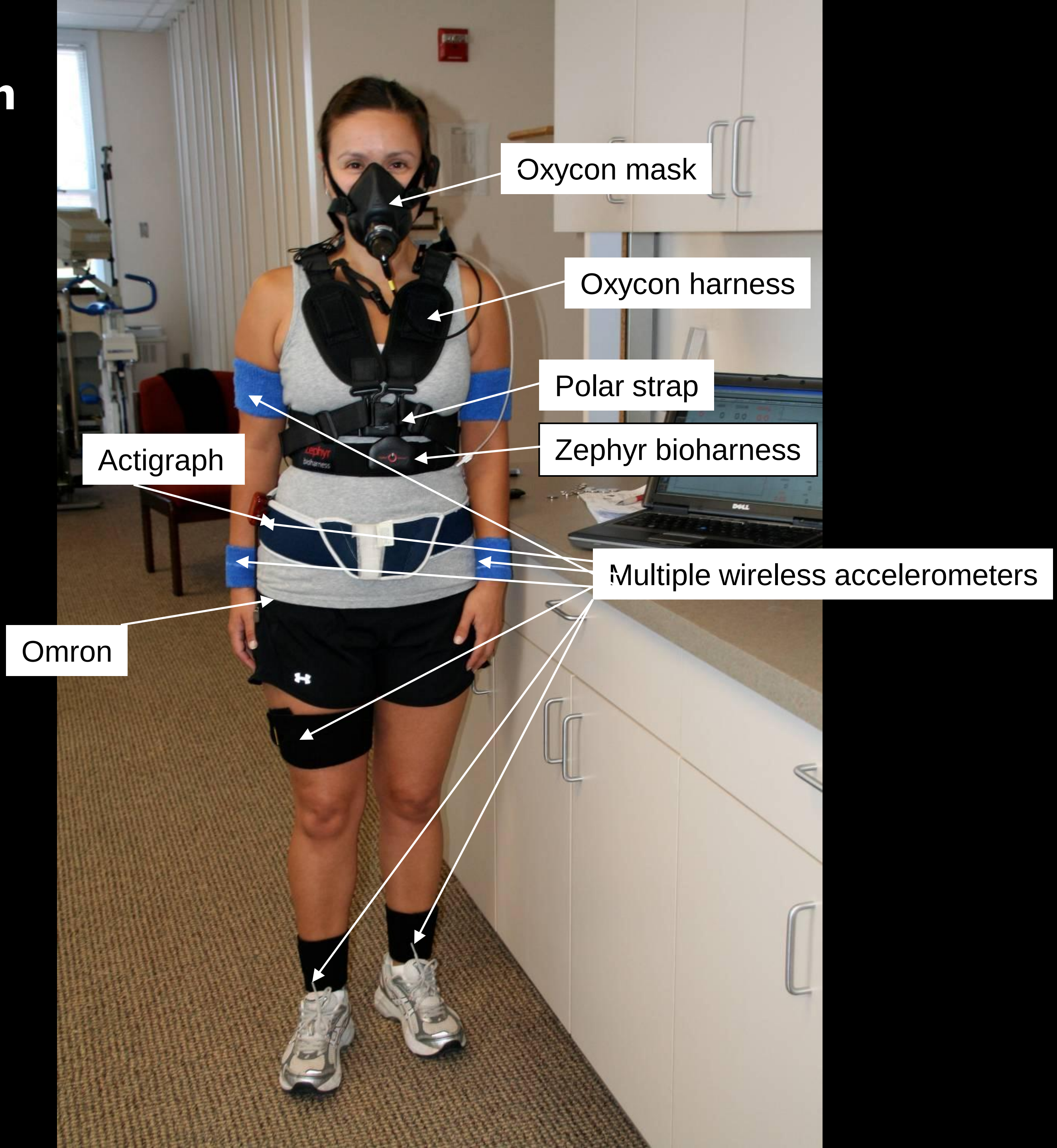
PR24	Prompt-Type:Audible prompt (Ringer on vibrate - vibrate prompt) Prompt-Time:2012-02-27 16:55:42.0 Response-Time:null

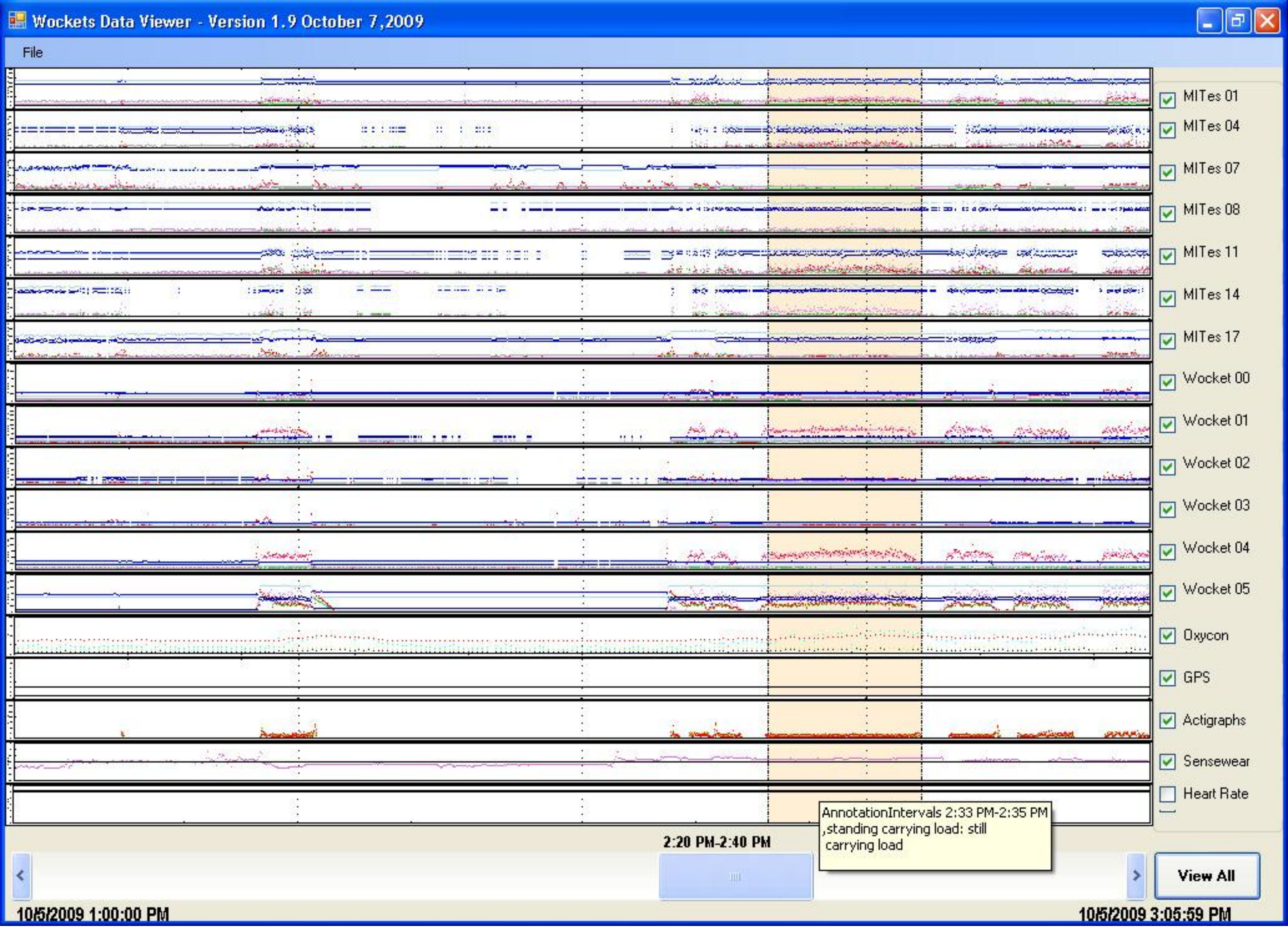
Working toward...

- 24/7 real-time knowledge of
  - Activity type
  - Duration
  - Intensity
  - Location
  - Other information gathered from phone
    - Communication
    - Social interaction

+ Self-reported contextual information

Controlled data collection with Stanford collaborators





Wockets Data Viewer - Version 1.9 October 7,2009
File
MITes 01
MITes 04
MITes 07
MITes 08
MITes 11
MITes 14
MITes 17
Wocket 00
Wocket 01
Wocket 02
Wocket 03
Wocket 04
Wocket 05
Oxycon
GPS
Actigraphs
Sensewear
Heart Rate
AnnotationIntervals 2:33 PM-2:35 PM ,standing carrying load: still carrying load
2:20 PM-2:40 PM
View All
10/5/2009 1:00:00 PM
10/5/2009 3:05:59 PM

Lab performance: Activity rec

		Subject Dependent	Subject Independent
Activities to recognize	**Random Guess (%)**	**Total Accuracy (%)**	**Total Accuracy (%)**
All (51)	1.9%	87.9	50.6
All with no intensities (31)	3.2%	91.4	72.0
Postures, ambulation and two MET intensity categories (11)	9%	96.5	81.3
Postures and Ambulation with no intensity (8)	12.5%	98.4	92.9
Postures (4)	25%	99.3	98.0

Lab validation experiments

- Lab
- Lab + some everyday activities
- "Obstacle course" datasets

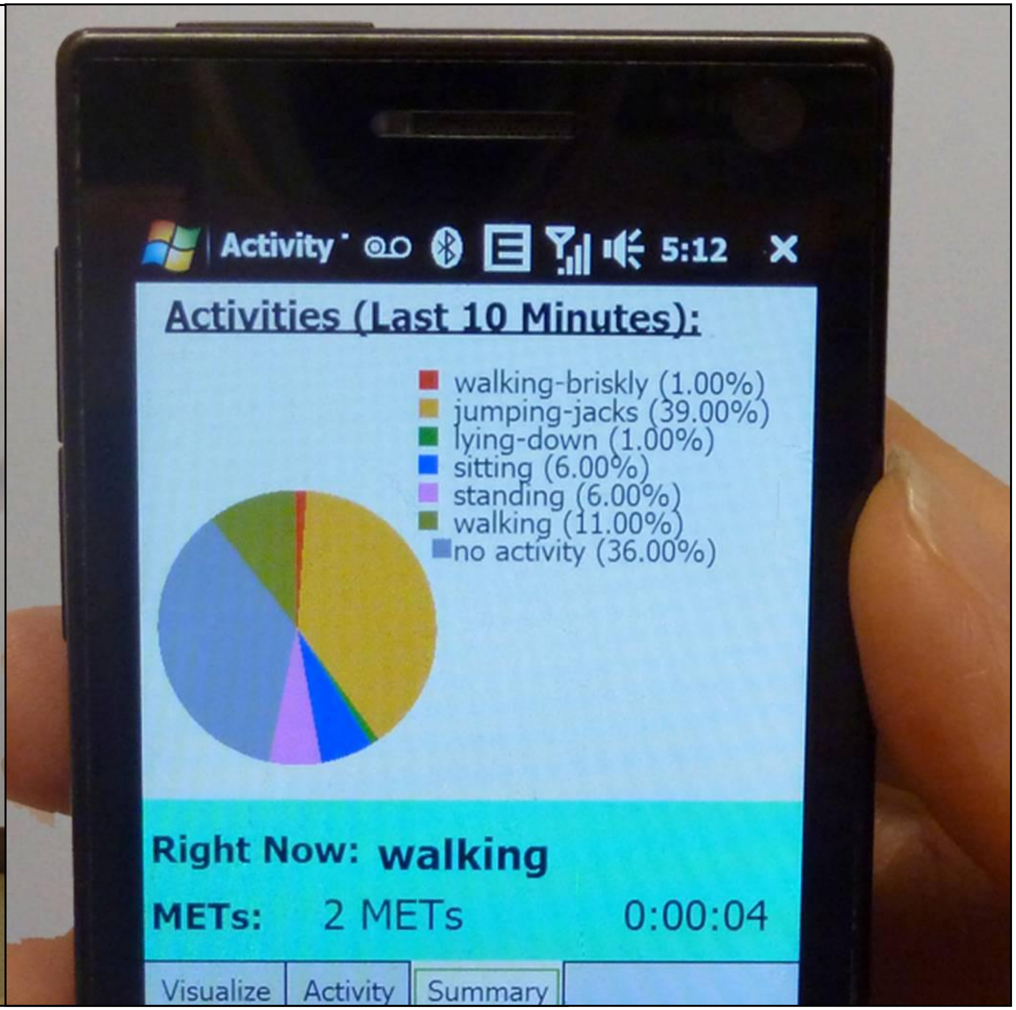
NHANES: hip to wrist and then ?

33 adults: Test wrist vs. ankle ambulation detection

	Wrist 12.8 s	4 s	2 s	Ankle 12.8 s	4 s	2 s
Overall accuracy (%)	**84.7**	**84.2**	**82.8**	**95.0**	**94.6**	**93.8**
Accuracy (ambulation)	87.2	87.4	87.1	99.5	99.1	98.8
Accuracy (cycling)	62.9	65.2	65.4	93.9	94.2	93.7
Accuracy (others)	81.6	77.0	72.6	81.6	78.7	76.7
Accuracy (sedentary)	91.2	90.6	88.9	96.0	96.1	95.3
F1-score (ambulation)	0.90	0.90	0.89	0.99	0.99	0.99
F1-score (cycling)	0.66	0.68	0.66	0.95	0.95	0.95
F1-score (others)	0.82	0.78	0.74	0.84	0.81	0.79
F1-score (sedentary)	0.88	0.87	0.86	0.95	0.95	0.94

Now: real-time implementation

Detect activity type in real-time



Open source/standards

- Open source
  - Access to hardware has been a barrier
  - Working to solve this

- Open standards
  - Collect/save raw data
  - Open algorithms
  - No proprietary “counts” to slow field

Wockets: last cost estimate

- In quantities of 100 (researchers build)
  - Wocket: $63
  - Band: $4.50
  - Charger: $28

  - System (without phone):
    4 Wockets, 4 bands, charger: ≈$298

    (Single Actigraph GT3X: $300+)

Are you scratching your head?

"Just a Bluetooth accelerometer"
"Why didn't you add a [pick a sensor]"

- Yes, but...
  - While each part is simple, the system is not; all design decisions are inter-related
  - Lab prototype is the easy part; robust deployment is the hard part!
  - Cost and field validation are key

Challenges we've had

- Bluetooth limitations on phones
- Avoiding feature/cost creep
- Thin+waterproof+inexpensive+low volume
- Battery life (on phones)
- Minimizing participant burden
- Remote data validation tools
- Robustness in all conditions

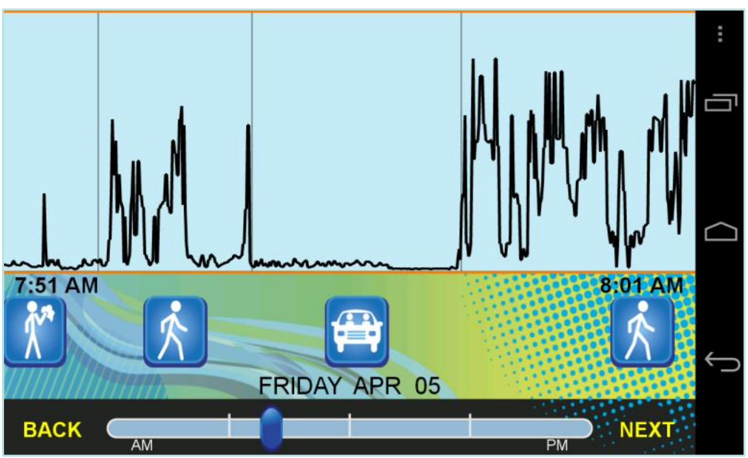
What health researchers say

- **Like** lower price than gold standard
- **Unsure** about new capabilities
  - Intrigued about improving what they measure
  - Uncertain about data-driven discovery and new information ("fishing expeditions")
- **Dislike** higher risk
  - Require validation studies
  - Want comparison with common measures

Planned validation study

- 40 subjects (considered small)
- Wear Wockets system daily for 4 months
  - Use remote compliance monitoring tools
  - Gold standard comparison tricky
- Continue wearing Wockets (up to 4 mo)
  - No prompting from staff
  - Phone encourages compliance

Remember: need self-report!



Teen activity measurement
with Genevieve Dunton at USC

- Use Wockets and/or phone's internal motion sensor to "chunk" day
- Data provide memory cues
- Easy to fill in gaps with precise timing

So what's coming?

- Using a variety of "sensors"...
  - Phone
  - Wearable
  - In-home
  - Data from environmental computers/systems
  - Sustainable, well-timed self-report questions

- Computer will incrementally build a rich, real-time model of behavior that enables better science and new interventions

Take away

- Mobile devices with real-time feedback create novel (and engaging?) behavioral **measurement** and **intervention** options that *can't be achieved without the technology*
- ***Just-in-time*** **delivery of tailored questions (CS-EMA)** may be important for behavior measurement/understanding
- New opportunities for how we do research being created

More info

- http://mhealth.ccs.neu.edu
- s.intille@neu.edu

Check out Northeastern's new transdisciplinary Ph.D. in Personal Health Informatics! (recruiting students/faculty)
http://phi.neu.edu