Micro-randomized Trials in Mobile Health

S.A. Murphy

Future of Data Science

MD2K Center of Excellence for Mobile Sensor Data-to-Knowledge

The Methodology Center
advancing methods, improving health

INSTITUTE FOR SOCIAL RESEARCH
UNIVERSITY OF MICHIGAN

MICHIGAN STATISTICS

mHealth

MD2K Smoking Cessation Coach

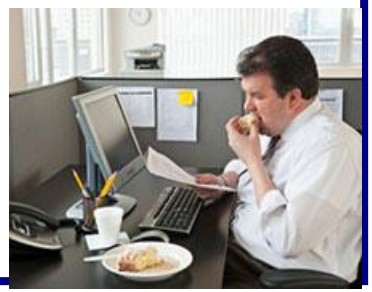
- Wearable chest and wrist bands measure activity, stress, cigarette smoking…….
- Supportive stress-regulation interventions available on smartphone 24/7
- In which contexts should the wrist band provide supportive “cue” and smartphone activate to highlight associated support?

mHealth

HeartSteps Activity Coach

- Wearable band measures activity, phone sensors measure busyness of calendar, location, weather, ...

- In which contexts should smartphone ping and deliver activity recommendations?



Data from wearable devices that sense and provide treatments

On each individual:

$$O_1, A_1, Y_2, \ldots, O_t, A_t, Y_{t+1}, \ldots$$

O_t: Context at tth decision time (high dimensional)

A_t : Action at tth decision time (treatment)

Y_{t+1} : Proximal Response (aka: Reward, Cost)

Data

1) Decision Times, *t*: Times at which a treatment can be pushed to user.

    1) Regular intervals in time (e.g. every 10 minutes)
    2) At user demand

HeartSteps: Approximately every 2-2.5 hours

Data

2) Observations of Context, O_t
   1) Passively collected (via sensors)
   2) Actively collected (via self-report)

HeartSteps: activity recognition, location, busyness of calendar, step count, usefulness ratings, adherence…….

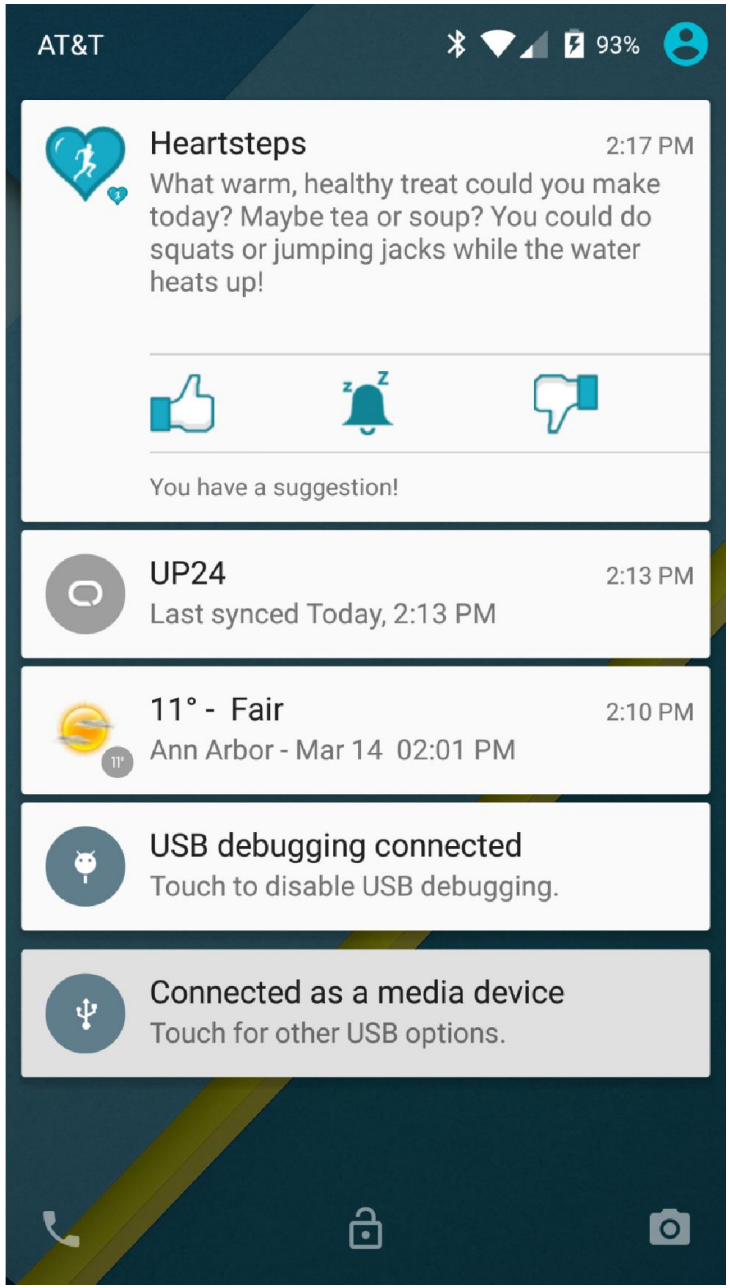
Treatment

3) Actions, A_t
    1) Type of Treatment
    2) Whether to provide a treatment

HeartSteps: Activity Recommendation

Activity Recommendation

No Message or



Data

4) Proximal Response, Y_{t+1}

HeartSteps: Activity (step count) over next 60 minutes.

Data Science mHealth Roadmap

1) Develop trial designs/data analytics for assessing if there are effects of the treatment actions on the proximal response. *experimental design*

2) Develop learning algorithms for use with resulting data to assess if there are delayed effects of the actions; assess if the effects vary by context. *causal inference*

3) Develop learning algorithms for using resulting data to construct a "warm-start" treatment policy. *batch RL*

4) Develop online training algorithms that will result in a Personalized Continually Learning mHealth Intervention *online RL*

Micro-Randomized Trial

Randomize between actions at decision times → Each person may be randomized 100's or 1000's of times.

- These are sequential, "full factorial," designs.
- Design trial to detect main effects.

Micro-Randomized Trial for HeartSteps

- 42 day trial
- Whether to provide an Activity Recommendation? $A_t \in \{0, 1\}$
- Randomization in HeartSteps

$$P[A_t = 1] = .4 \quad t = 1, \ldots, T$$

Micro-Randomized Trial

Time varying potentially intensive/intrusive treatment actions → potential for accumulating habituation and burden

→

Allow effect of the treatment actions on proximal response to vary with time

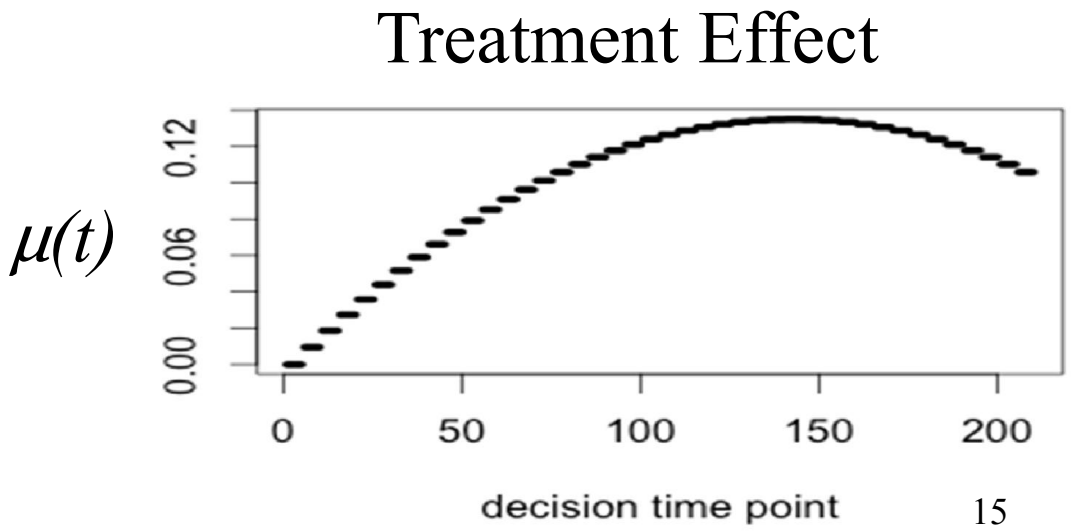
Availability & the Treatment Effect

- Treatment actions can only be delivered at a decision time if an individual is *available*.

- The effect of treatment at a decision time is the difference in proximal response between *available* individuals assigned an activity recommendation and *available* individuals who are not assigned an activity recommendation.

Treatment Effect

- $\mu(t)$ denotes the treatment effect at decision time t.
- What does this treatment effect, $\mu(t)$, mean???



Sample Size Calculation

- We calculate the number of subjects to test H_0: no effect of the action, i.e.,

$$H_0 : \mu(t) = 0, t = 1, 2, ...T$$

- Size to detect a low dimensional, smooth alternate H_1.
  - Example: H_1: $\mu(t)$ quadratic with intercept, μ_0, linear term, μ_1, and quadratic term μ_2 and test

$$\mu_0=\mu_1=\mu_2=0$$

Sample Size Calculation

Alternative hypothesis is low dimensional

$\longrightarrow$ assessment of the effect of the activity recommendation uses contrasts of *between subject responses* + contrasts of *within subject responses*.

--The required number of subjects will be small.

Sample Size Calculation

Given a specified power to detect the smooth alternative, a false-positive error probability, and the desired detectable signal to noise ratio, we use statistics, aka “data science!” to derive the sample size.

HeartSteps Sample Sizes
True-positive power=.80,
False-positive error=.05

Signal/Noise ratio over 42 days	Sample Size for 70% availability or 50% availability
0.06 standard deviations	81 or 112
0.08 standard deviations	48 or 65
0.10 standard deviations	33 or 43

Steps Toward Long Term Goal

1) Develop trial designs/data analytics for assessing if there are effects of the actions on the proximal response. *experimental design*

2) Develop learning algorithms for use with resulting data to assess if there are delayed effects of the actions; assess if the effects vary by context. *causal inference*

3) Develop learning algorithms for using resulting data to construct a "warm-start" treatment policy. *batch RL*

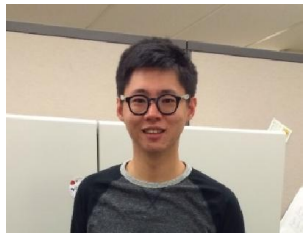
4) Develop online training algorithms that will result in a Personalized Continually Learning mHealth Intervention *online RL*

General Challenges

- How to reduce the amount of self-report data (How might you do this?)
- Missing data
- Detection of outcomes using sensor data
- Predictors of latent states, predictors of outcomes (using sensor data)
- Measuring treatment fatigue without causing treatment fatigue.
- Incorporating delayed rewards

Collaborators!



















samurphy@umich.edu

The mHealth Dream!

"Continually Learning Mobile Health Intervention"

- Help you achieve your health goals
  - Help you better trade off long term benefit with short term momentary pleasure
- The ideal mHealth intervention
  - will be there when you need it and will not intrude when you don't need it.
  - will adjust to unanticipated life challenges

Why Micro-Randomization?

- Randomization is the gold standard for providing data to assess the effect of a treatment action.
- Sequential randomizations will enhance replicability and effectiveness of treatment policy learned from data.