What Is Mobile Health?

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Definitions of mHealth

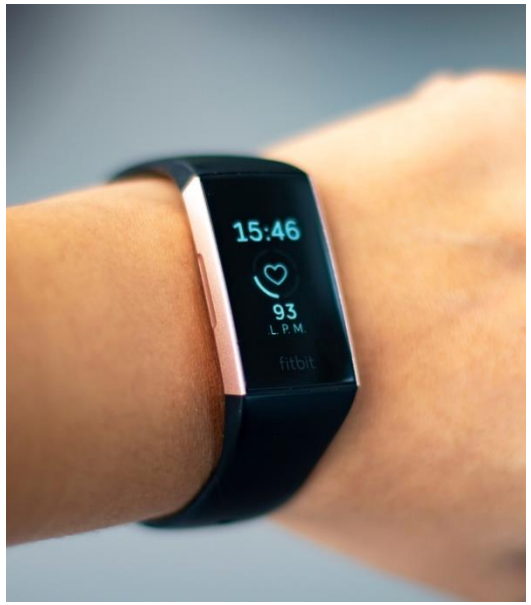
"The use of mobile and wireless devices to improve health outcomes, health care services, and health research" – National Institutes of Health

"Medical and public health practice supported by mobile devices" – World Health Organization

"The monitoring and sharing of health information via mobile technology" – Business Insider

“Traditional” Mobile Devices

Smartphones



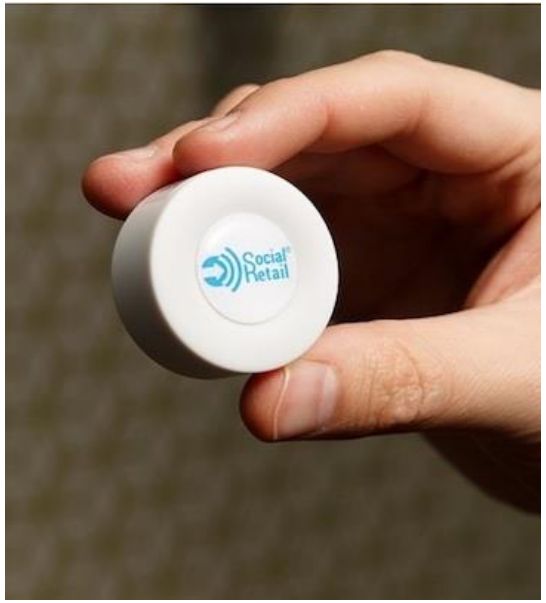
Smartwatches &
Fitness Trackers

Mobile / “Feature”
Phones

Palm Pilots / PDAs

“Cutting Edge” Mobile Devices

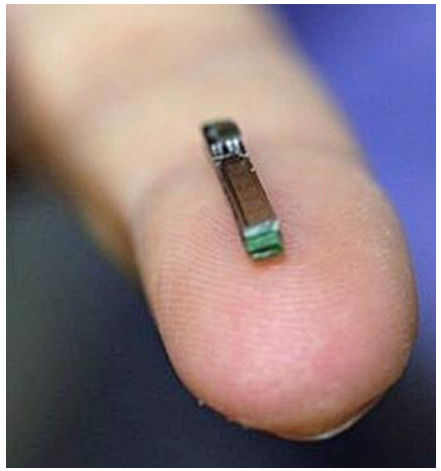
Smart Glasses



Bluetooth Beacon

Smart Rings

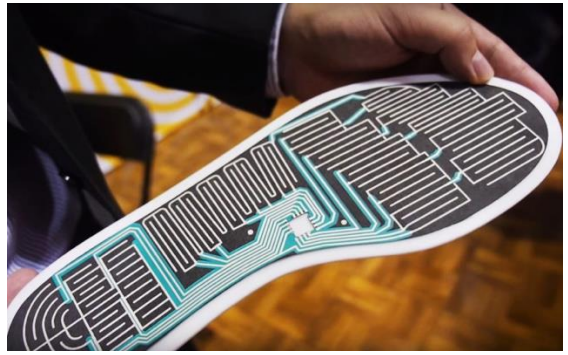
“Emerging” Mobile Devices



Implantables

Smart Contact Lenses

Smart Fabrics



Smart Shoes

Skin Sensors

Other Ubiquitous Technologies for Health

- Desktops and laptops
- Mobile phone attachments
- Wireless sensing
- Smart speakers
- Environment sensors

Advantages of Mobile Devices

1. Smartphone penetration is high
   - 67% of the global population has a mobile phone; 48% has a smartphone (BankMyCell ‘21)
   - In sub-Saharan Africa, 86% of people will have a SIM connection, and 65% of them will come from a smartphone (GSMA ’20)
   - Consistently high across genders, ethnicities, socio-economic status
   - Potentially quicker path to major impact

Note: This data does not mean we can assume that everyone has a mobile phone

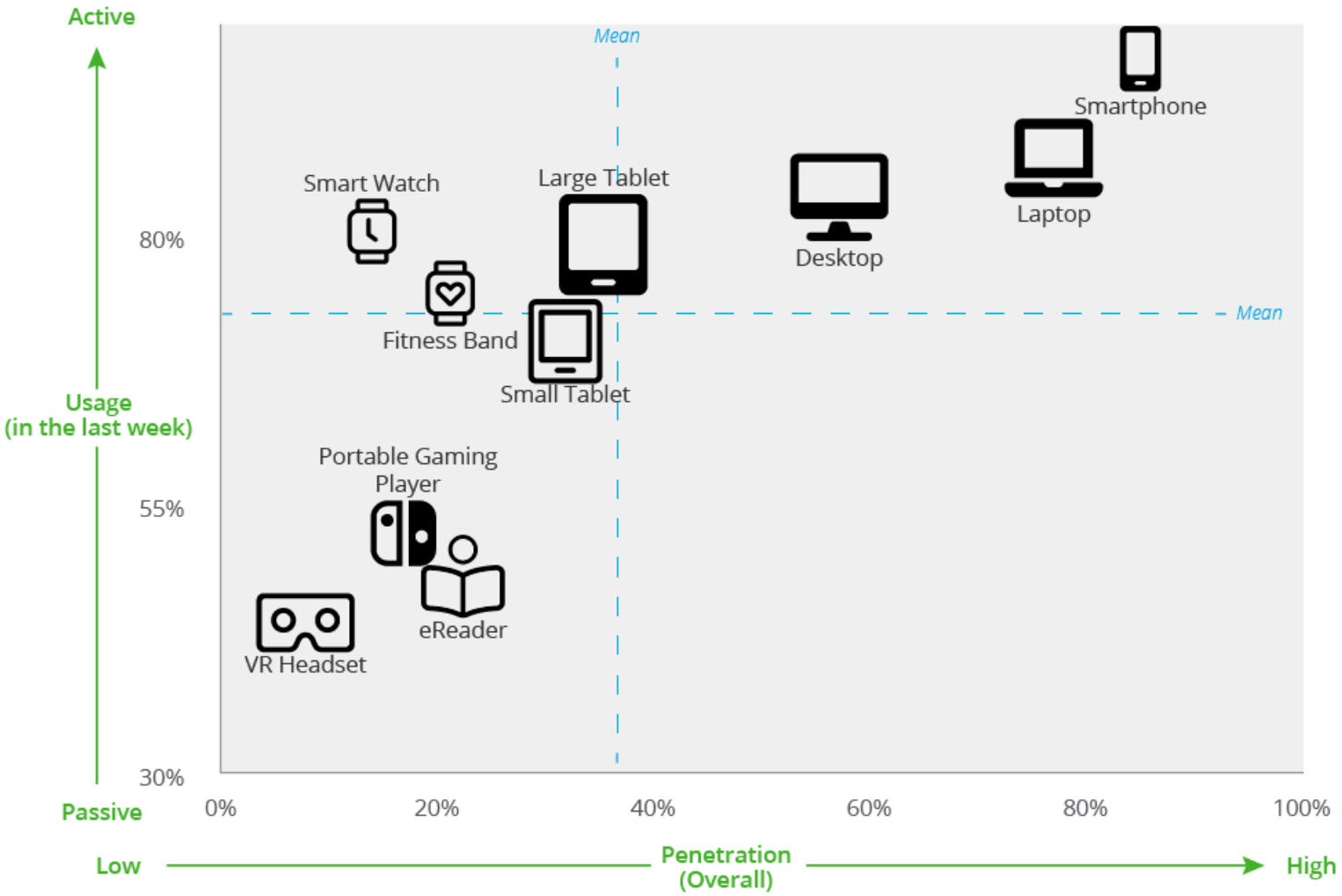
Advantages of Mobile Devices

2. Mobile devices are often nearby
    - People keep their smartphone is within arm's reach 50% of the time and in the same room 90% of the time (Dey et al. '11)
    - People wear their smartwatches for ~9 hours per day (Jeong et al. '17)
    - More opportunities for sensing, interaction, and intervention

Advantages of Mobile Devices

3. Mobile devices are familiar interfaces
    - Many people are willing to keep their phone in working condition
    - Many people are willing to upgrade their phone on a semi-regular basis, leading to better hardware over time
    - Can leverage common interaction patterns and familiar interfaces to make usable apps

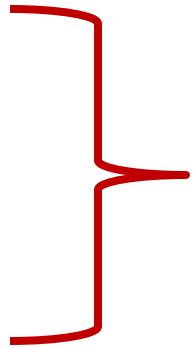
Advantages of Mobile Devices



Deloitte Global Mobile Consumer Survey: [United States 2018 Statistics]

Alex's Categories of mHealth

1. Education, reminders, and data management
2. Population health
3. Physiological signals
4. Momentary symptom assessment
5. Continuous health management



Focus of this course

1. Education, Reminders, and Data Management

Leverages the communication capabilities of mobile devices to support existing practices for healthcare management

- Improved access to health information
- Multimedia guidebooks for remote medical decision-making
- Reminders for medication adherence and clinic visits
- Digital forms for facilitating data entry

1. Education, Reminders, and Data Management

Example: Ngabo et al. '12

Motivation: Maternal deaths in low- and middle-income countries are often due to delays in health-related decision-making as a result of adverse events

Opportunity: SMS can be used to scaffold communication between community health workers and mother-infant pairs

2. Population Health

Leverage trends across communities to understand population-level trends

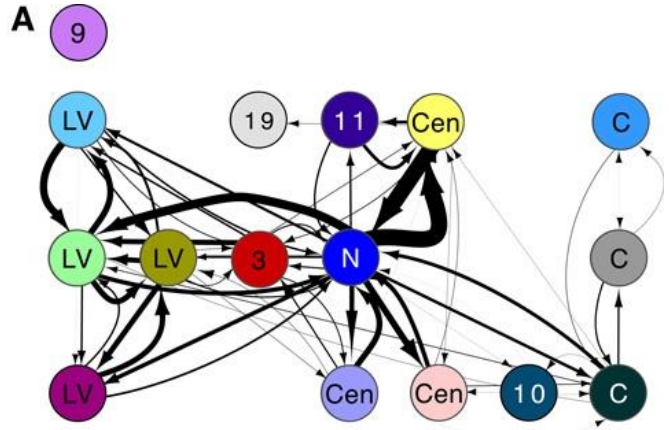
- Urban mobility and access to green space
- Epidemic monitoring and contact tracing
- Community-level predictors of long-term health

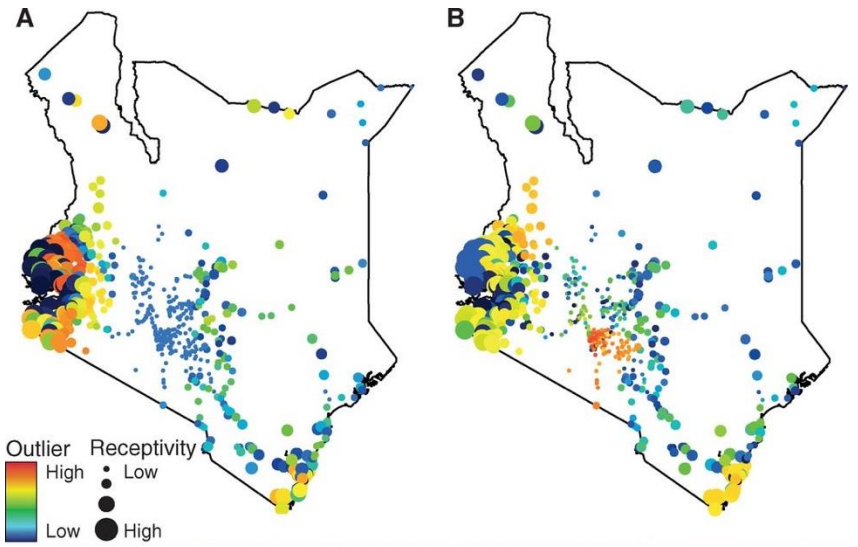
2. Population Health

Example: Wesolowski et al. '13

Motivation: Identifying the "sources" and "sinks" of malaria transmission due to human travel would improve malaria control in Kenya

Opportunity: Smartphone mobility data (i.e., cell tower connections) can be used to approximate travel to and from major cities and villages





3. Physiological Signals

Measure continuous, real-time indicators of health that apply to the population at large

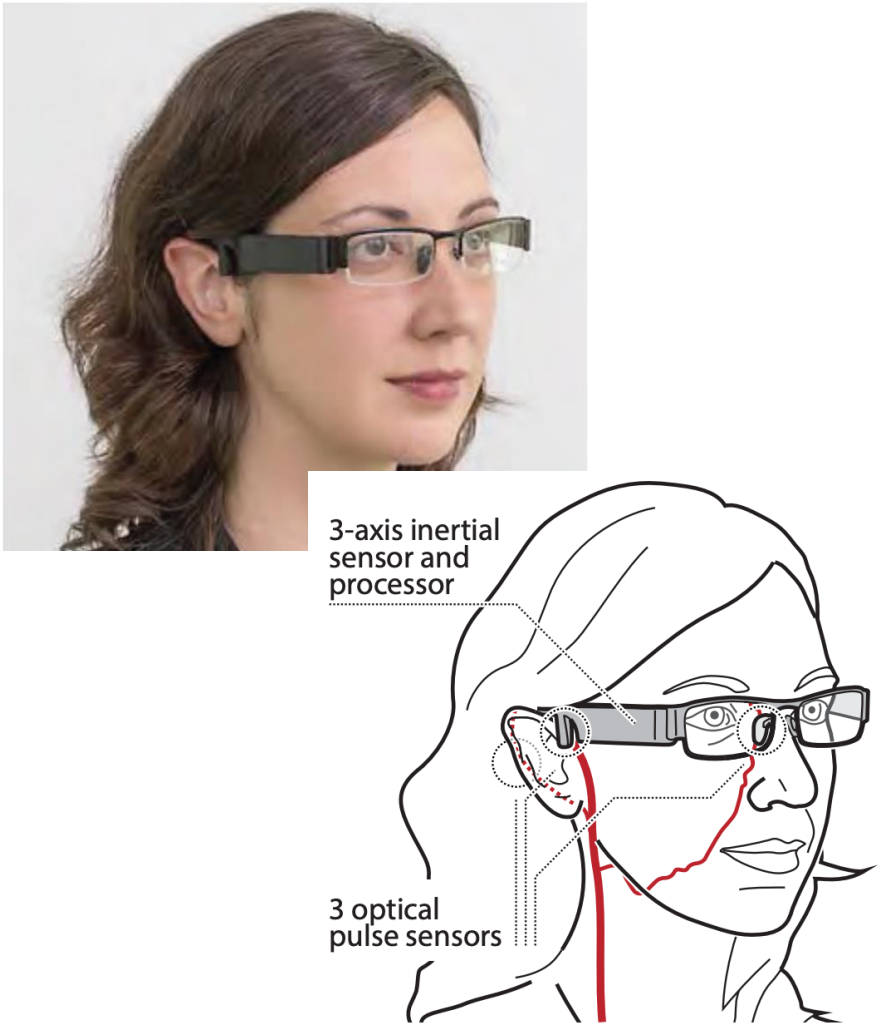
- Heart rate (HR), heart rate variability (HRV), and stress
- Blood pressure
- Maximal oxygen consumption (VO_2 max)
- Oxygen saturation (SpO_2)
- Step count
- Gait speed and stride length

3. Physiological Signals

Example: Holz and Wang '17

Motivation: Blood pressure naturally varies throughout the day, so any one-time measurement is likely to be confounded

Opportunity: Photoplethysmography (PPG) sensors can be embedded in glasses to continuously measure pulse transit time, which is related to blood pressure



4. Momentary Symptom Assessment

Ask users to go through an explicit procedure with their phone (e.g., perform a gesture, take a selfie) to take a measurement

- Finger tapping task for fine motor control
- Timed up-and-go (TUG) walking task for mobility
- Place finger over the camera or selfie recording for PPG
- Picture of skin lesion for skin cancer identification

4. Momentary Symptom Assessment

Example: de Greef et al. ’14

Motivation: Neonatal jaundice is subjective and difficult for new parents to identify

Opportunity: The smartphone’s camera can accurately and objectively measure colors, which can be converted to a bilirubin measurement

5. Continuous Health Management

Leverage passive sensing to continuously measure physiological signals, behaviors, and contextual variables that may indicate a person's health state

- Diabetes monitoring
- Cough detection and classification
- Influenza-like symptom monitoring
- Stress / mental health management
- Smoking events
- Just-in-time adaptive interventions

5. Continuous Health Management

Example: Wang et al. ‘16

Motivation: Schizophrenics experience dynamic changes and episodes at a frequent rate yet cannot be constantly monitored by clinicians

Opportunity: Smartphones can measure behavioral, environmental, and contextual indicators of mental health status (e.g., activity level, sleep duration, location)

Momentary vs. Continuous Assessment

Momentary (Active) Assessment

+ More control over where, when, and how data is collected
– Requires users to remember to test themselves
– May require expertise to be used properly

Continuous (Passive) Assessment

+ Designed to collect data passively without needing user involvement
+ Richer time resolution of data
+ Enables opportunistic interventions
– Limited control over where, when, and how data is collected
– More things can go wrong due to higher measurement frequency

Alex's Categories of mHealth

1. Education, reminders, and data management
2. Population health
3. Physiological signals
4. Momentary symptom assessment
5. Continuous health management

Challenges in mHealth

Note: Phones can be augmented with attachments

Trade-offs in hardware sophistication

	Dedicated Hardware	Low-End Smartphones	High-End Smartphones
Deployability	Need strategy to distribute at scale	Most ubiquitous	Limited to tech-savvy
Instrumentation	Can be specifically designed to requirements	Limited sensors	Better sensors
Control	Complete control over hardware and software	At the mercy of smartphone manufacturers and developers	

Which endpoints should we target for which use cases?

Challenges in mHealth

Designing for non-expert users

	Research Study	Clinical Deployment	Smartphones
Device Operator	A researcher or study coordinator familiar with the data	Doctors, EMTs, and nurses with training	Ordinary people without training
Environment	Controlled lab environment	Hospital lighting, consistent noise	Anywhere

How do we ensure everything data is high quality?

How do guide people to use mHealth tools properly?

Challenges in mHealth

Designing for non-expert users

Doctors are trained to interpret medical information, ordinary people are not

Even the "simplest" data can lead people to illogical conclusions

- Example on weight scales: Kay et al. '13

How are people supposed to interpret their data?

What are people supposed to do with their results?

Challenges in mHealth

Not all smartphones are created equal

- Different sensor specifications
  - Sampling rate
  - Camera color sensitivity
- Different physical layout of sensors
  - Relative position of microphone and speaker
  - Relative position of camera and flash
  - Relative position of vibration motor and accelerometer
- Different levels of API access

How do we ensure mHealth apps work for all phones?

Challenges in mHealth

Deciding on the most appropriate baseline(s)

Selecting an appropriate baseline for model training and evaluation depends on more than just accuracy

Example: Imagine we are developing a system to measure stress throughout the day. What would be the best approach for comparison?

- Salivary cortisol test: accurate, but extremely inconvenient
- Stress survey (PHQ-9): very subjective, but easy to complete

Are we training models on the right labels?

Are we comparing our systems to the right baseline?

Challenges in mHealth

Endless potential for bias

Examples of demographic bias

- **PPG:** skin tone
- **Cough counting:** voice characteristics across genders
- **Pupil measurements:** eye color

Other examples

- **Step counting:** device placement (e.g., pockets but not purses)
- **Any project:** device model
- **Any project:** data collection environment for targeted populations

How do we identify and mitigate these potential biases?

Challenges in mHealth

- Trade-offs in hardware sophistication
- Designing for non-expert users
  - Data collection
  - Interpretation
- Not all smartphones are created equal
- Deciding on the most appropriate baseline(s)
- Endless potential for bias

Some Venues to Explore

In no particular order:

- ACM HEALTH
- ACM IMWUT
- EAI PervasiveHealth
- JMIR mHealth & uHealth
- NPJ Digital Medicine

Resources

mHealth for Development
(United Nations & Vodafone Foundations)

mHealth and Applications
(Choe et al. '21)

Challenges in Realizing Smartphone-Based Health Sensing
(Mariakakis et al. '19)

Questions?