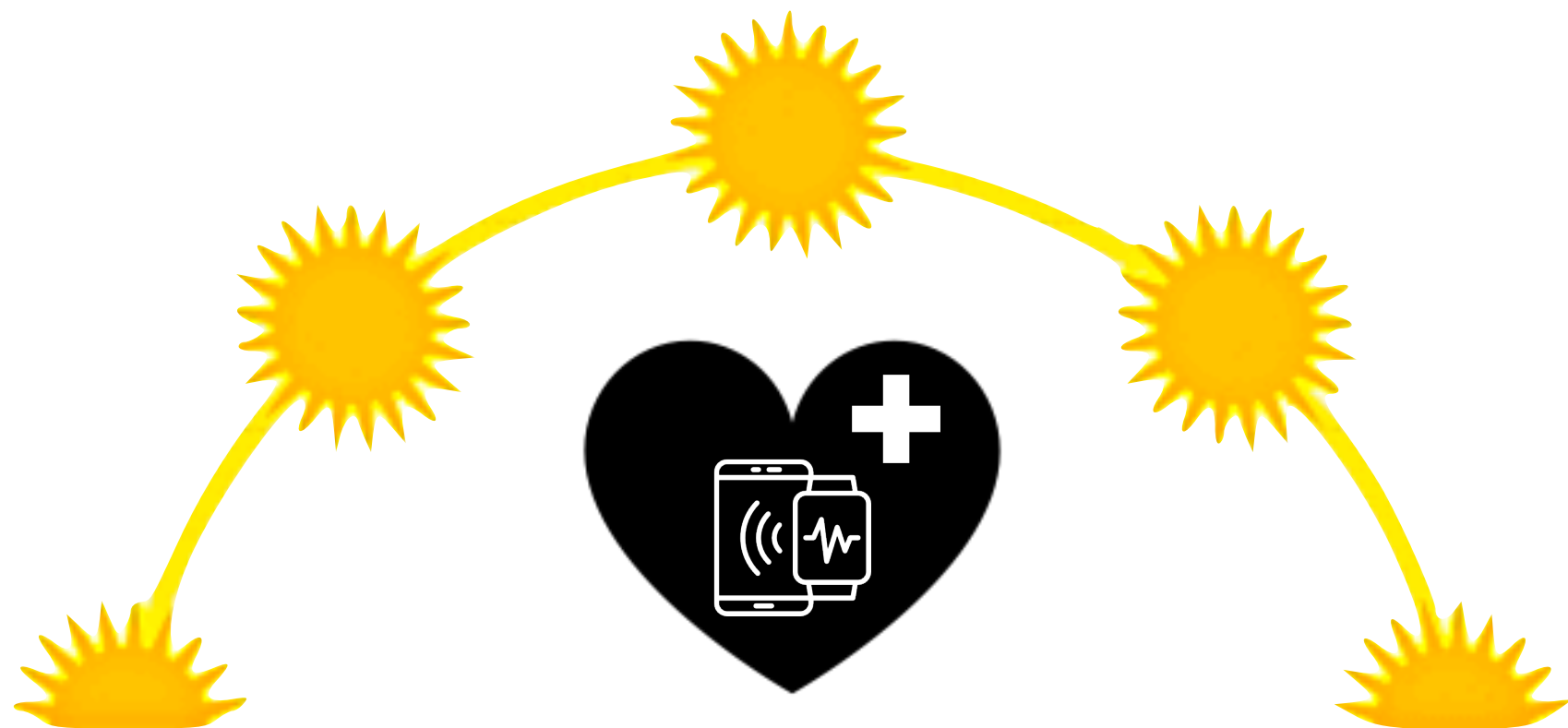


Mobile and Sensor Technology as a Tool for Health Measurement, Management, and Research with Aging Populations

Elizabeth Murnane, emurnane@stanford.edu

December 12, 2019

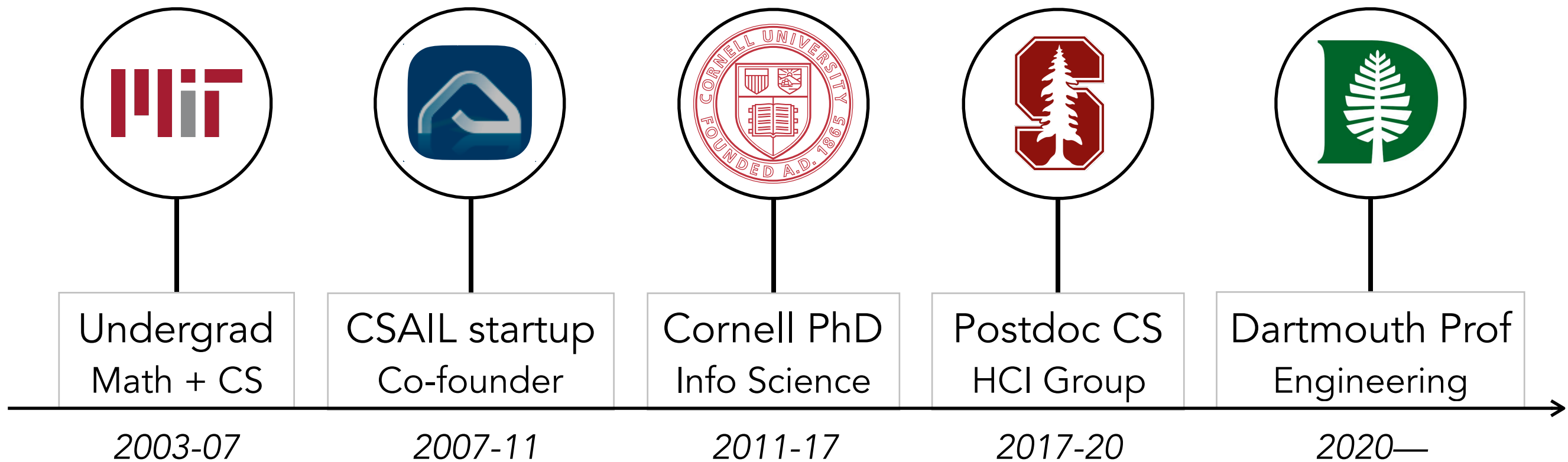


Today's talk

- Background and motivation
- The data pipeline of mHealth technology
- Data collection techniques & trade-offs
- Translating data to insight, informatics, and interventions
- Concluding remarks & group discussion

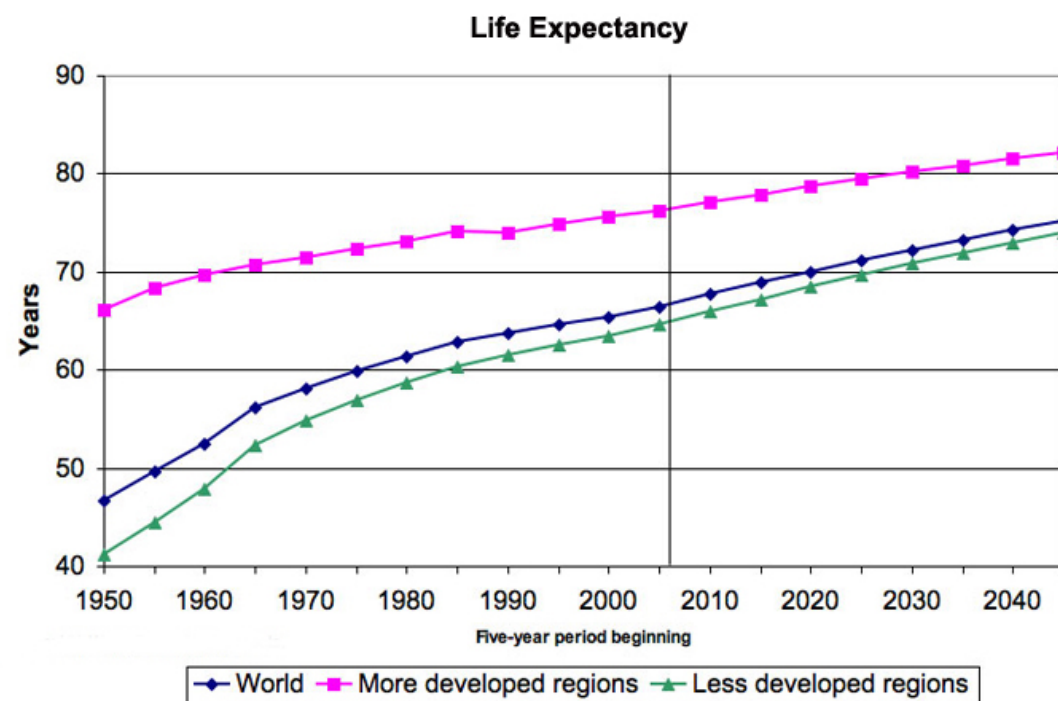
Background & motivation

Personal background & research focus



My research **designs, engineers,** and **studies the impact** of human-centered **technologies** that empower people in managing various aspects of their daily lives and **wellbeing**

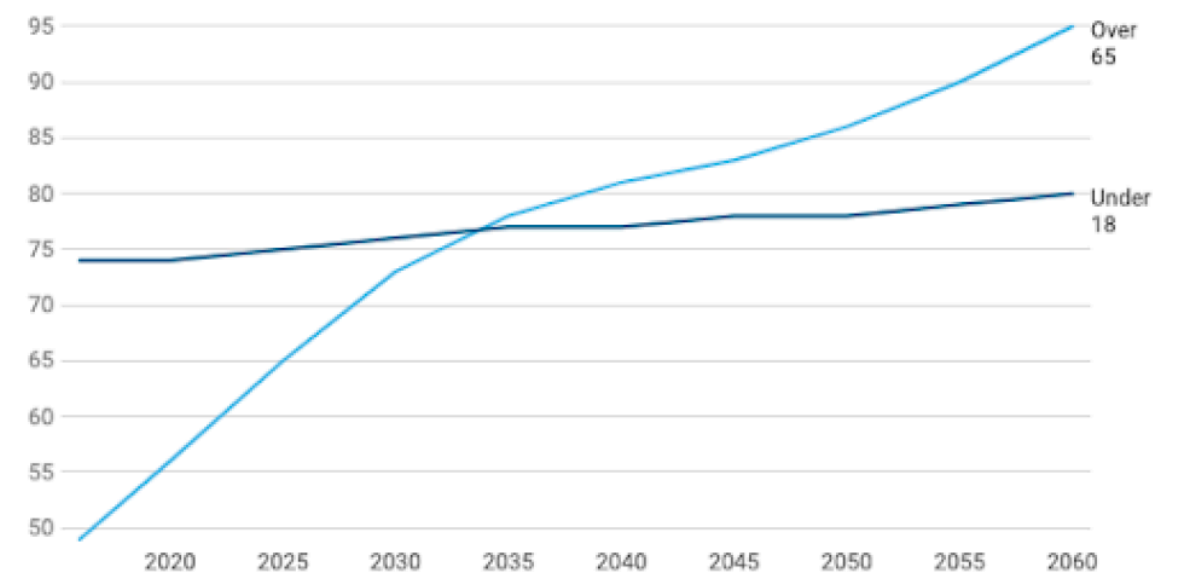
By 2050, number of adults 65+ expected to double
and account for 1/5 of the global population



Life expectancy
is up

U.S. Population Predictions for Seniors and Children

Population values in millions



Age distribution
is shifting

Sources: National Center for Health Statistics,
U.S. Census Bureau, World Health Organization

While a huge achievement, aging societies also present novel challenges to healthcare

As the lifespan grows, so do rates for noninfectious diseases, mental health problems, and age-related declines:

70%

of global burden
of disease

3/4

of deaths
worldwide

\$47

trillion in spending
by 2030

*Sources: Centers for Disease Control and Prevention,
World Health Organization, World Economic Forum*

For **older adults**, the occurrence of these conditions is even higher and estimated to continue growing

Of people 65 years and above:

80%

have 1 or more
chronic illness

75%

have 2 or more
chronic illnesses

2/3

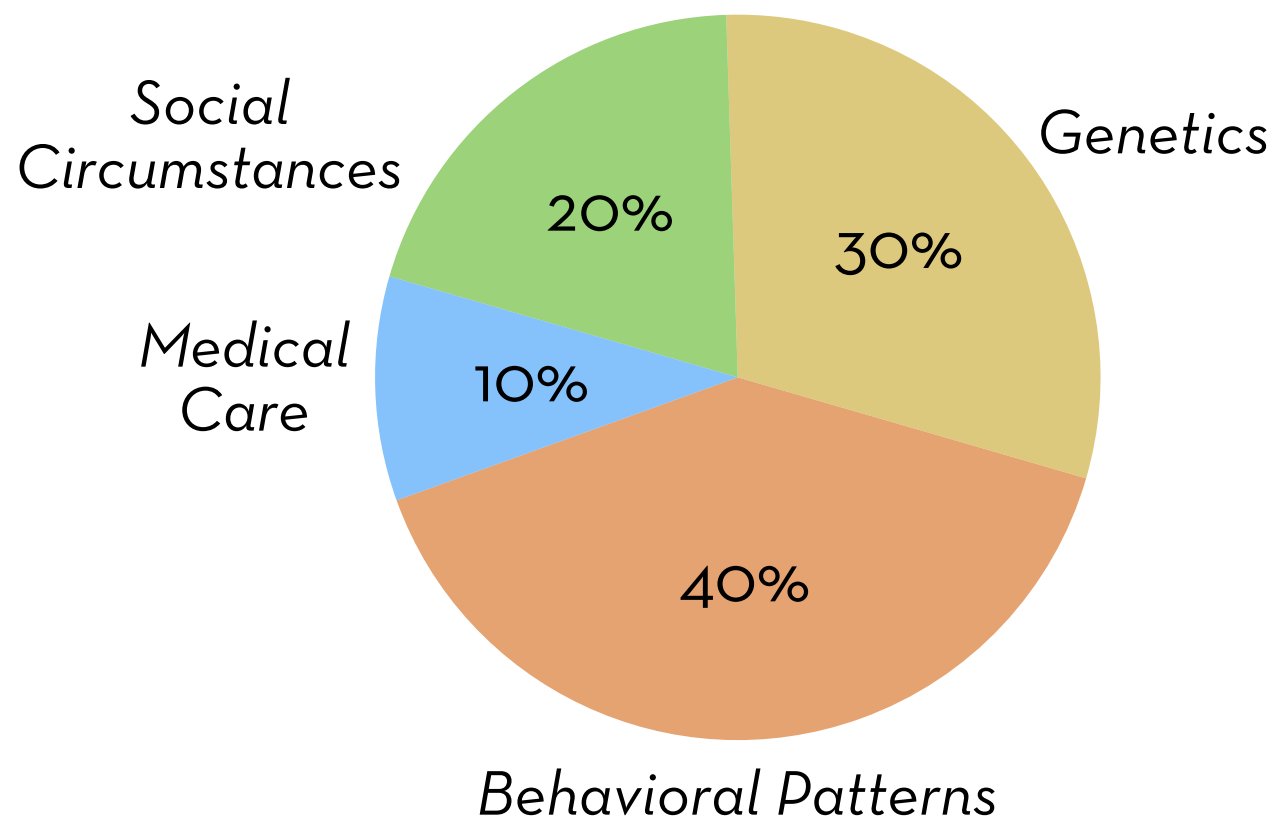
don't receive the
care they need

*Sources: American Association of Retired Persons,
National Council on Aging, National Institute of Mental Health*

Behavior contributes the **most** to **disease** development, progression, and outcome

The top **risk factors** for premature death all relate to **lifestyle choices**

Factors Influencing Health



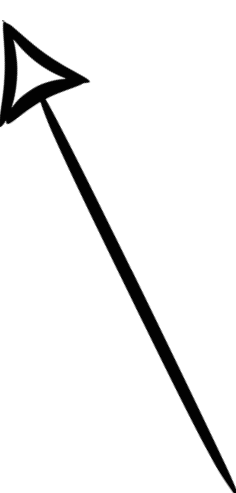
High BMI, excessive alcohol, inactivity, poor diet, smoking



Sources: Centers for Disease Control and Prevention, World Health Organization

“the single greatest opportunity to improve health and reduce premature deaths lies in personal behavior”

*Prof. Steven Schroeder, MD,
former RWJ President*



and promote
flourishing throughout
the lifespan, including
its **later stages**

A paradigm shift in how we approach health research and care

The age of behavior change & prevention



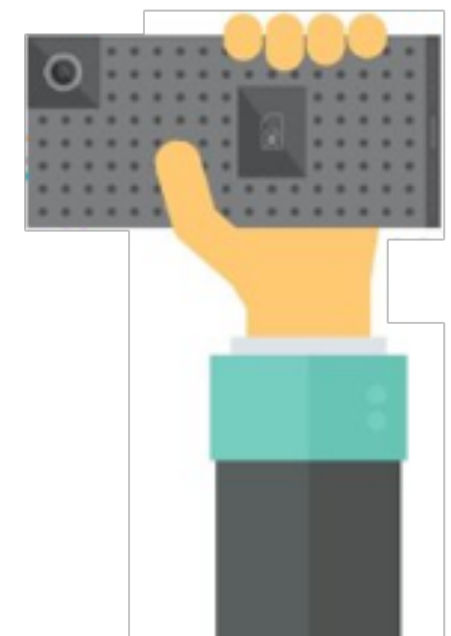
The person as the nexus of health management



The power of mobile technology...

... to enable health care that is

- low cost
- continuous
- personalized
- scalable



Access and attitudes

3/4

of people **65+** own
a **cellphone**

1/2

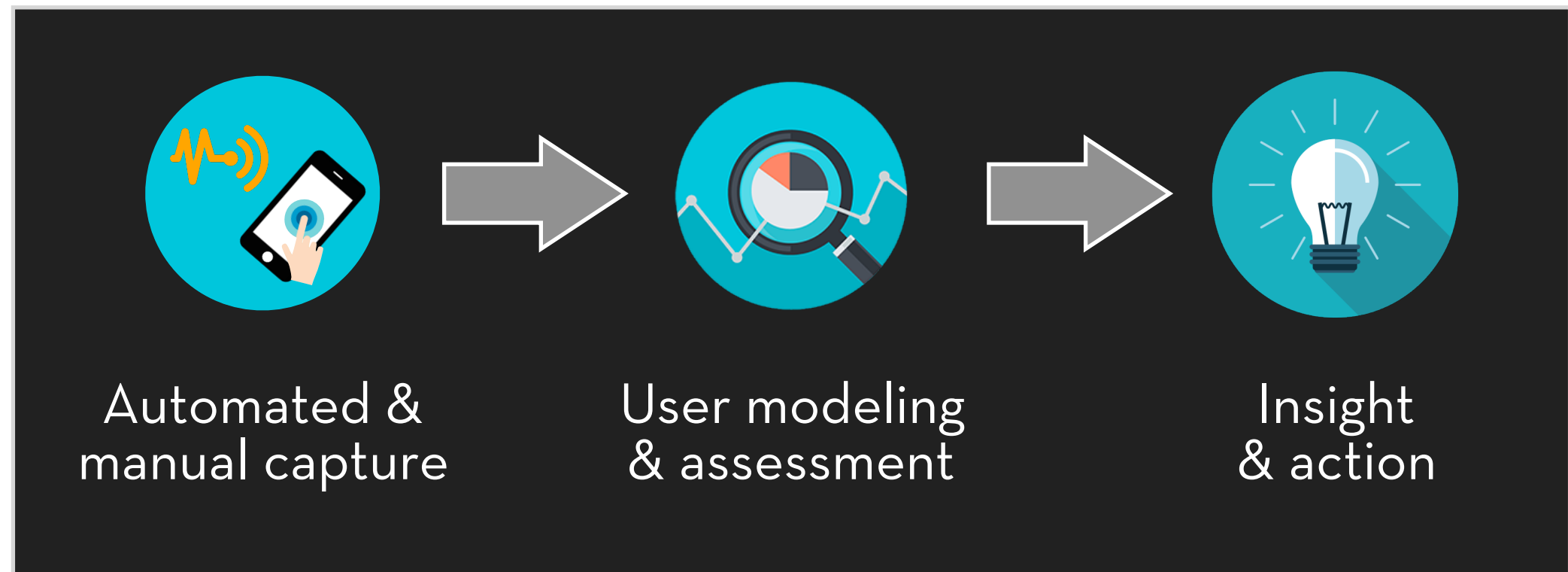
of people **75+** own
a **cellphone**

1/5

of people **65+** own
a **smartphone**

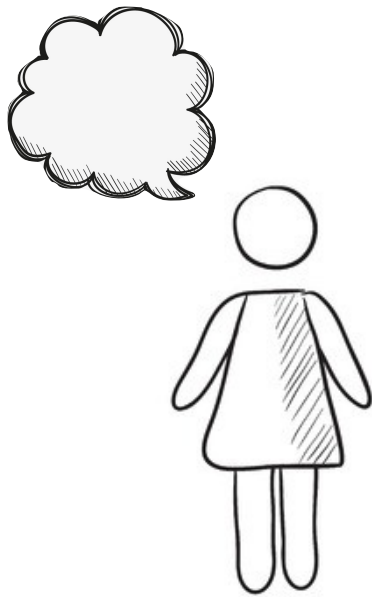
- Stereotypes that older adults are unable and unwilling to try new technologies is a **misconception**
- Studies find older adults exhibit open-minded **receptivity** and willingness towards the use of mHealth technologies
- But also perceive that tools aren't designed to **suit their abilities**
- Low adoption may be due to **design failures**, not people's disinterest

The data pipeline of mHealth technology

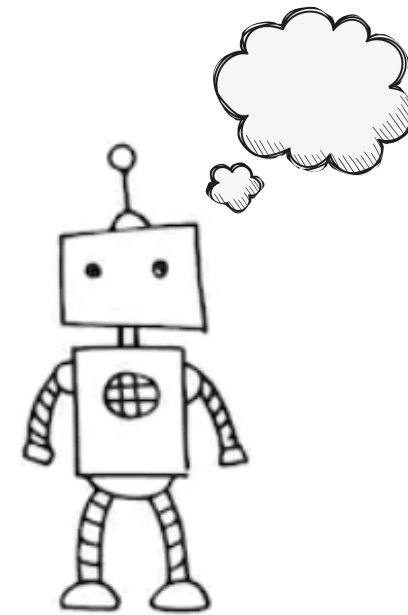


Data collection techniques & trade-offs

Manual & passive strategies

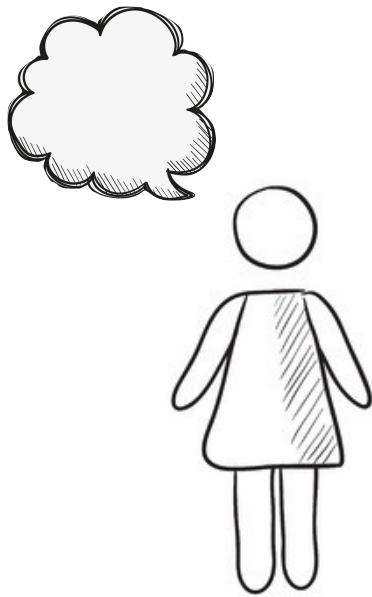


Subjective
self-report

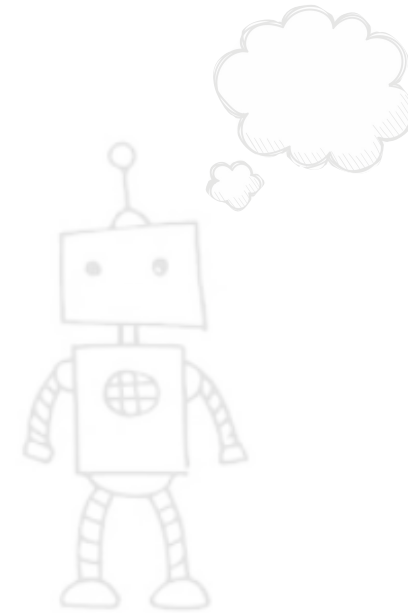


Automated
sensing

Manual & passive strategies

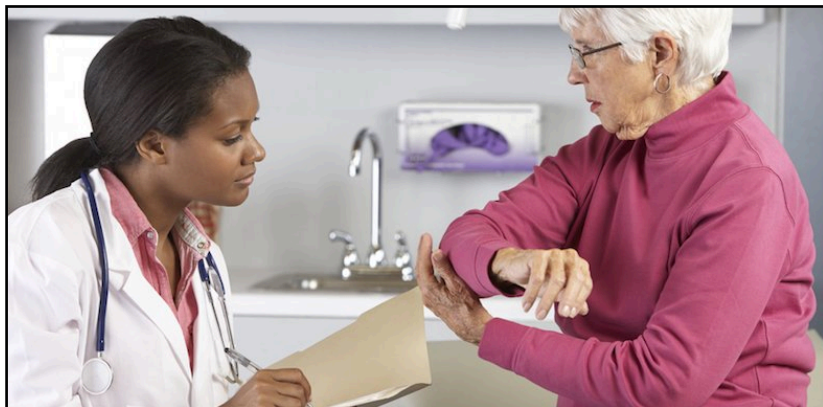


Subjective
self-report



Automated
sensing

Traditional approaches to health reporting face limitations related to recall, accuracy, and adherence



During doctor visits

Complete in the Morning	Today's date (include month/day/year):	Monday*			
	Time I went to bed last night:	11 p.m.			
	Time I woke up this morning:	7 a.m.			
	No. of hours slept last night:	8			
	Number of awakenings and total time awake last night:	5 times 2 hours			
	How long I took to fall asleep last night:	30 mins.			
	Medications taken last night:	None			
Complete in the Evening	How awake did I feel when I got up this morning? 1—Wide awake 2—Awake but a little tired 3—Sleepy	2			
	Number of caffeinated drinks (coffee, tea, cola) and time when I had them today:	1 drink at 8 p.m.			
	Number of alcoholic drinks (beer, wine, liquor) and time when I had them today:	2 drinks 9 p.m.			
	Nap times and lengths today:	3:30 p.m. 45 mins.			
	Exercise times and lengths today:	None			
	How sleepy did I feel during the day today? 1—So sleepy had to struggle to stay awake during much of the day 2—Somewhat tired 3—Fairly alert 4—Wide awake	1			

Daily diaries

SRM II-5												
Directions: • Write the ideal target time you would like to do these daily activities. • Record the time you actually did the activity each day. • Record the people involved in the activity: 0 = Alone; 1 = Others present; 2 = Others actively involved; 3 = Others very stimulating												
Date (week of): Feb 18 - 24 2013												
Activity	Target Time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday				
		Time	Time	Time	Time	Time	Time	Time				
		People	People	People	People	People	People	People				
Out of bed	6:30 a.m.	8:00 a.m. 0	6:15 a.m. 0	8:00 a.m. 0	6:45 a.m. 0	7:00 a.m. 0	8:00 a.m. 0	7:00 a.m. 0				
First contact with other person	8:40 a.m.	9:00 a.m. 2	8:00 a.m. 1	11:00 a.m. 2	8:30 a.m. 2	11:00 a.m. 2	1:00 p.m. 1	2:30 p.m. 3				
Start work/school/volunteer/family care	8:40 a.m.	10:00 a.m. 2	8:10 a.m. 2	11:40 a.m. 1	8:30 a.m. 2	11:40 a.m. 1	9:00 a.m. 0	7:00 a.m. 0				
Dinner	5:00 p.m.	6:00 p.m. 0	7:00 p.m. 0	5:40 p.m. 0	5:30 p.m. 0	5:30 p.m. 0	5:30 p.m. 0	6:00 p.m. 0				
To bed	12:00 p.m.	2:10 p.m. 0	3:00 p.m. 0	12:30 p.m. 0	2:00 a.m. 0	1:00 a.m. 0	1:45 a.m. 0	12:00 p.m. 0				
Rate MOOD each day from -5 to +5 -5 = very depressed +5 = very elated		+1	0	-1	+1	-1	-1	-2				

Paper instruments

Supporting momentary assessment (EMA) and experience sampling (ESM) with technology



+

Name: _____
Date: _____
Dose: _____

1 DAILY PAIN CHART (Insert the points on your Daily Pain Chart to your medical team on an when and why your pain level changes. Every day, your team will review this chart.)

PAIN LEVEL	0	1	2	3	4	5	6	7	8	9	10
12am											
1pm											
2pm											
3pm											
4pm											
5pm											
6pm											
7pm											
8pm											
9pm											
10pm											
11pm											
12am											

2 DAILY PAIN LOG (Insert the points on your Daily Pain Chart to your medical team on an when and why your pain level changes. Every day, your team will review this chart.)

Medication Name/Dose	0pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am
#1													
#2													
#3													
#4													
#5													

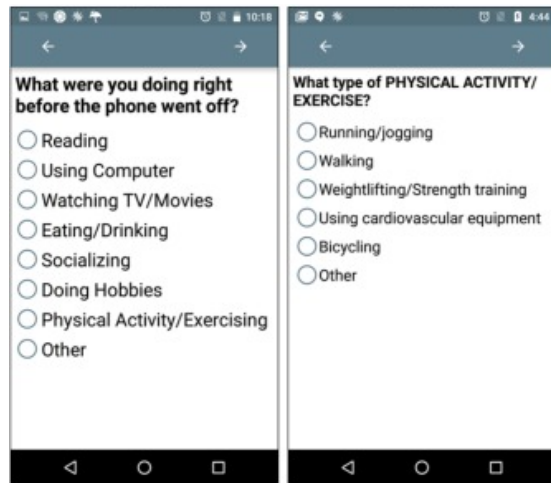
NON-DRUG THERAPIES (other than prescription or other medication)

ACTIVITIES/EXERCISES

COMMENTS AND MORE INFORMATION: Make notes for and about notes with your healthcare provider, side effects from treatments you may be experiencing, and any problems you are having coping with your pain. You may also want to write more about some of your answers on the previous page.

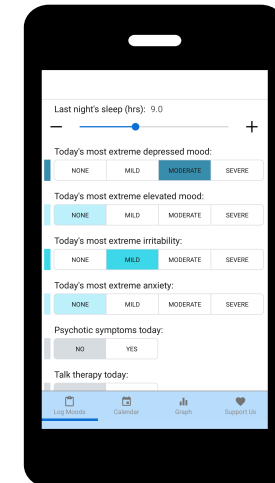
Initially, reminders to track were delivered on devices such as pagers or through cellphone text messages, though the recording itself was still made on paper

Large focus today on smartphone-based reporting given its ubiquity and support for rich interactions



The image shows two side-by-side smartphone screens displaying activity tracking forms. The left screen asks 'What were you doing right before the phone went off?' with radio button options: Reading, Using Computer, Watching TV/Movies, Eating/Drinking, Socializing, Doing Hobbies, Physical Activity/Exercising, and Other. The right screen asks 'What type of PHYSICAL ACTIVITY/ EXERCISE?' with radio button options: Running/jogging, Walking, Weightlifting/Strength training, Using cardiovascular equipment, Bicycling, and Other.

Physical activity



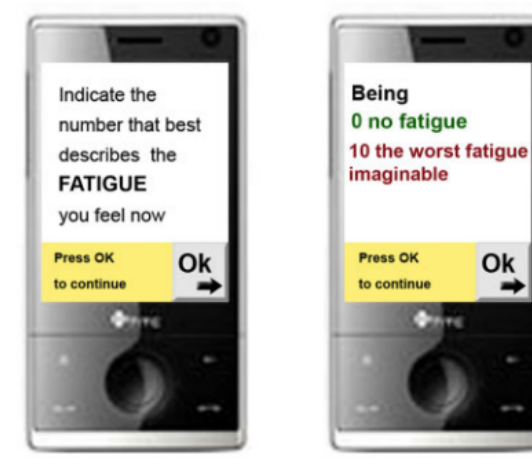
The image shows a smartphone screen with a mental health tracking interface. It includes a slider for 'Last night's sleep (hrs): 9.0', and several sections for mood and anxiety levels (NONE, MILD, MODERATE, SEVERE) for depressed mood, elevated mood, irritability, and anxiety. It also has checkboxes for 'Psychotic symptoms today' (NO, YES) and a text field for 'Talk therapy today:'. A bottom navigation bar contains icons for Log, Calendar, Graph, and Support Us.

Mental health



The image shows two side-by-side smartphone screens for diabetes management. The left screen has tabs for BG, Meds, Food, Activity, and A1C. It displays a date picker for 'May 12, 2012 8:44 PM', a notes field, and a BG (mg/dL) input field. Below is a table of BG readings for the week of May 10-14. The right screen is titled 'New Record' and 'Date' with an 'Accept' button. It shows a date picker for 'February 25, 2012' and a table of BG readings for the week of February 23-29.

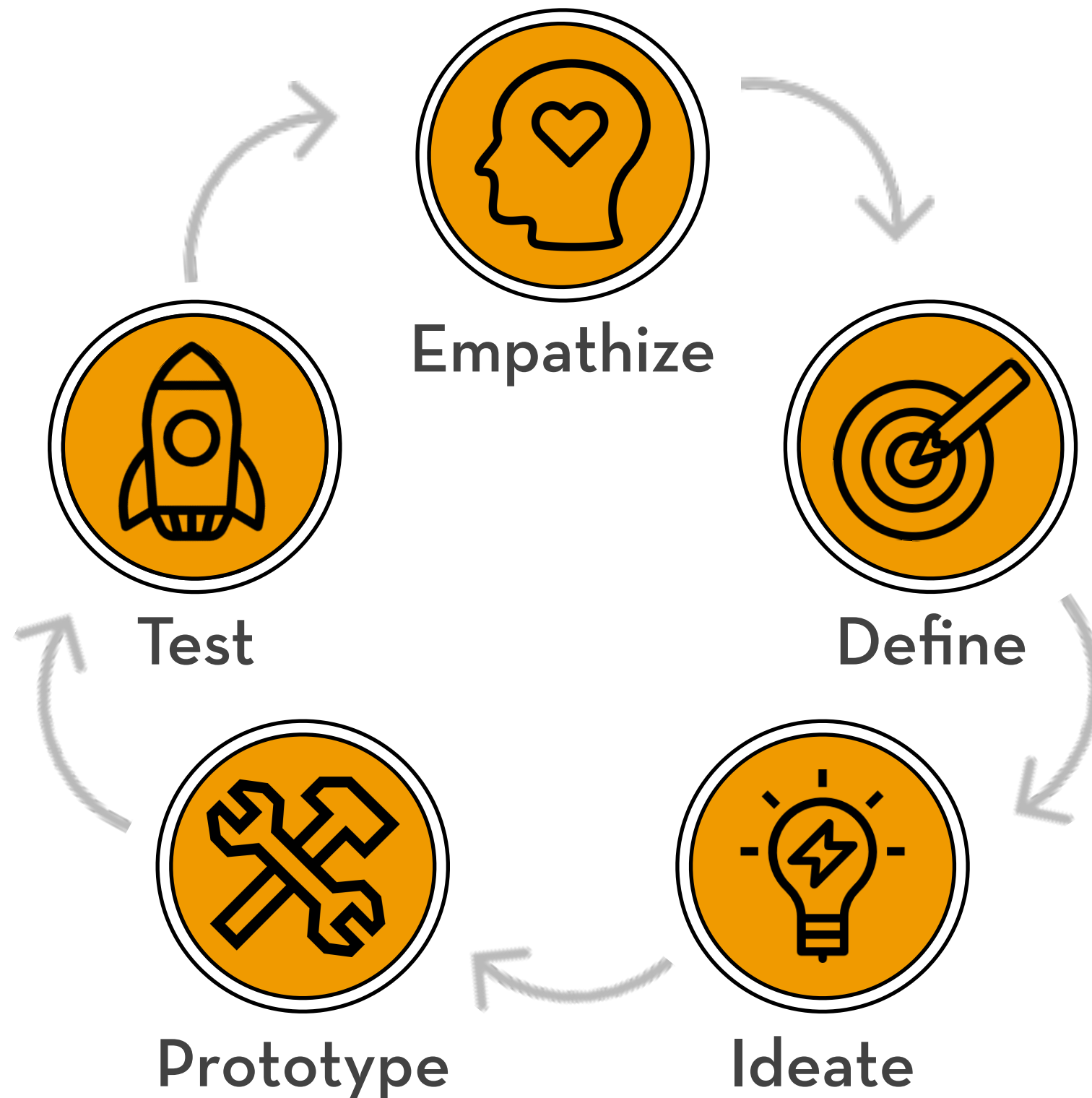
Diabetes



The image shows two side-by-side smartphone screens for chronic pain and fatigue assessment. The left screen asks 'Indicate the number that best describes the FATIGUE you feel now' and has a 'Press OK to continue' button. The right screen shows the result: 'Being 0 no fatigue 10 the worst fatigue imaginable' with '0' in green and '10' in red. It also has a 'Press OK to continue' button.

Chronic pain and fatigue

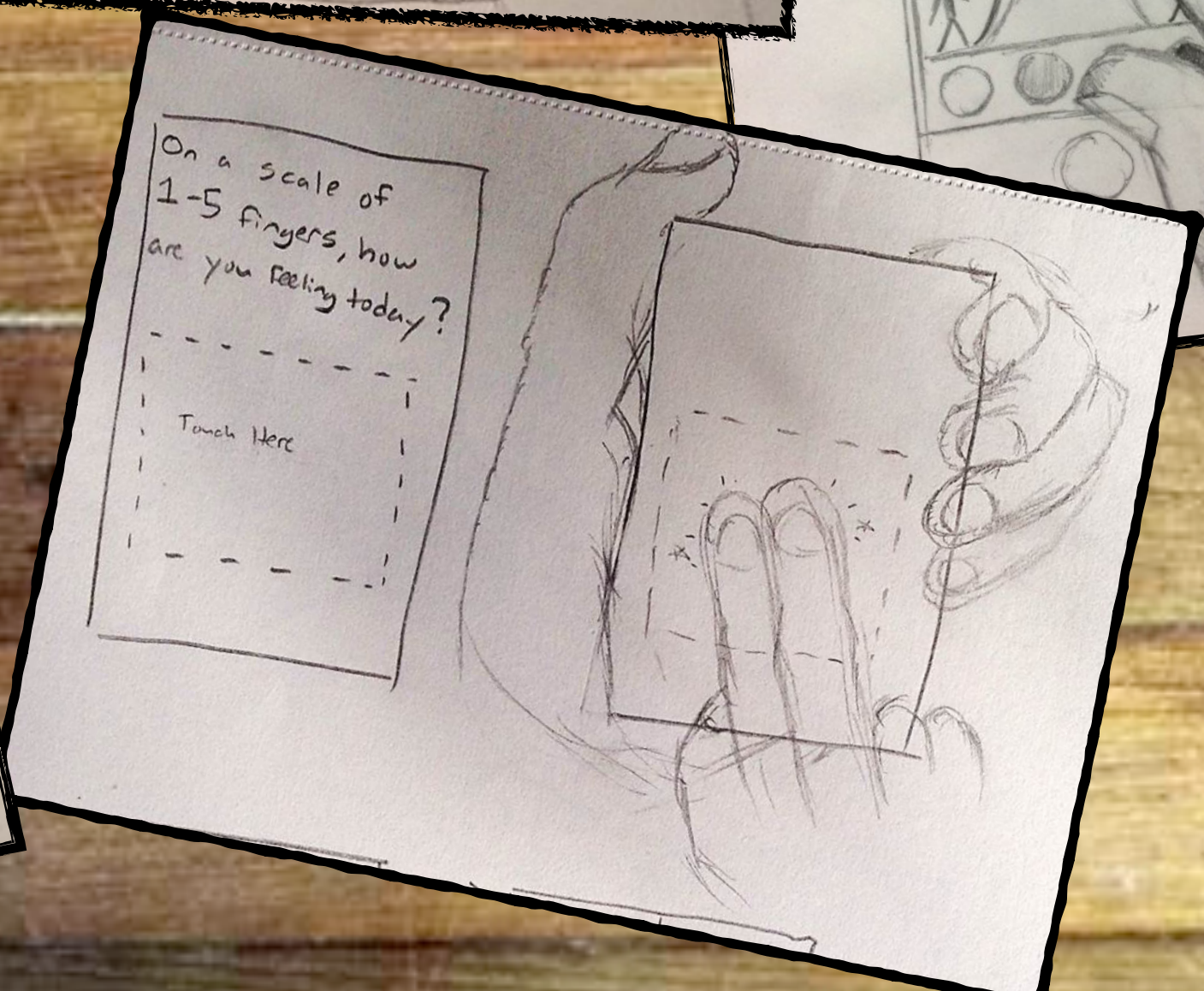
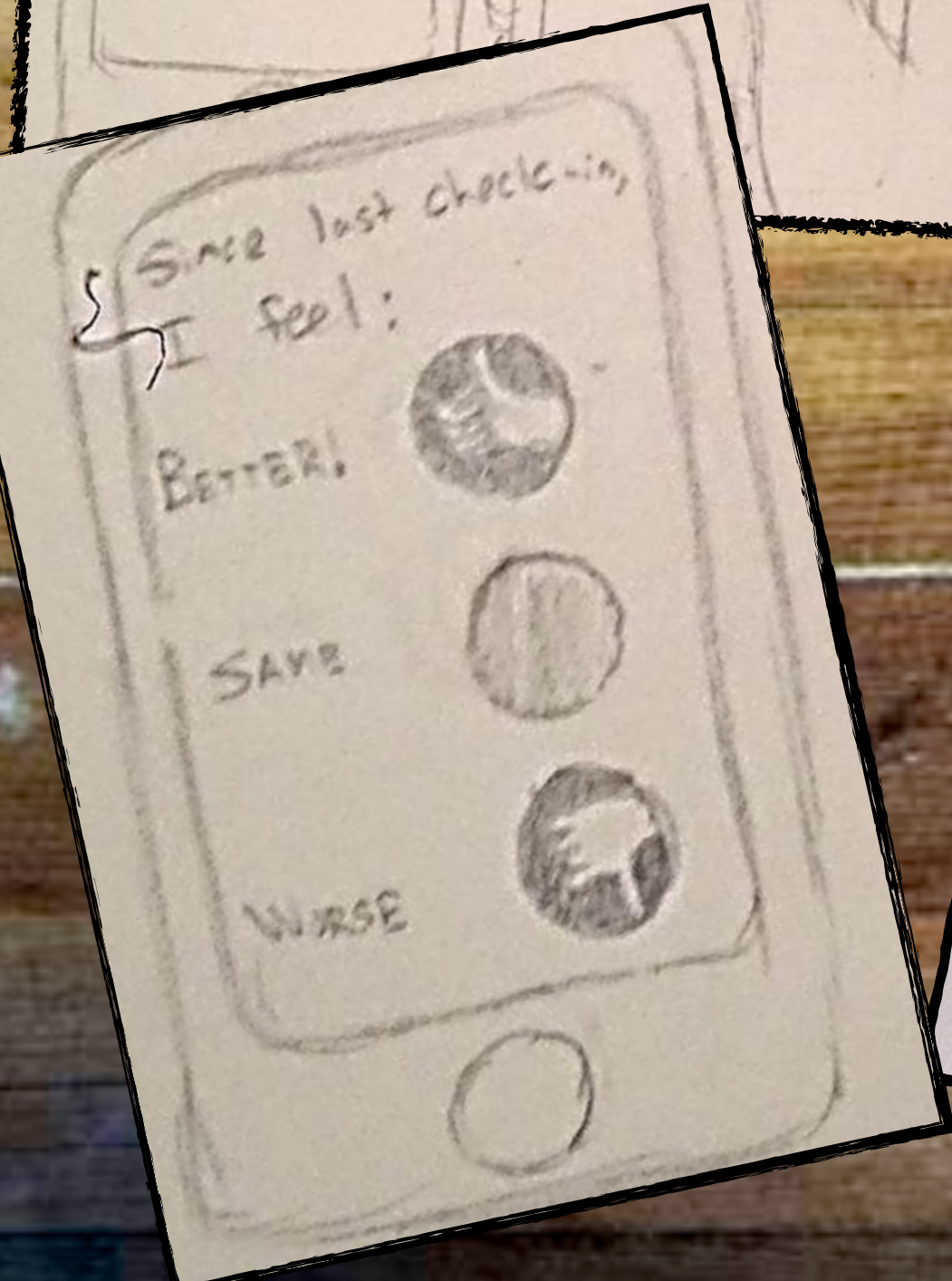
Brief design dive: pain self-assessment



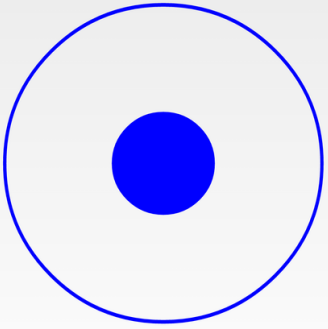
Design requirements

(Derived from the self-report and usability literatures, consultations with clinicians and target users, and our experience working with older adults and developing EMA systems)

- ❑ Low-burden and high-accessibility interactions
- ❑ Smartphone medium
- ❑ Repeated use
- ❑ Cognitive translation
- ❑ Eliciting potentially distressing experiences



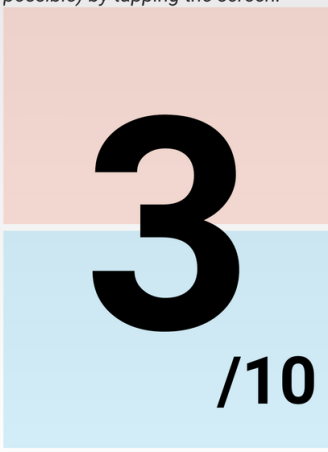
1 Please touch-and-hold the screen to report your current pain level from empty circle (no pain) to the full circle (worst pain possible):



Reset

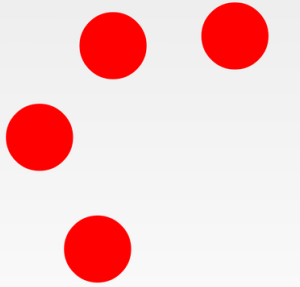
Submit

2 Please report your current pain level (0 = no pain, 10 = worst pain possible) by tapping the screen.



Submit

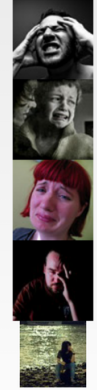
3 Please touch the screen with 1 to 5 fingers to report your current pain intensity level (5 = worst pain ever):



Submit

4 Please tap on the image that best represents your current pain level:

Worst pain imaginable

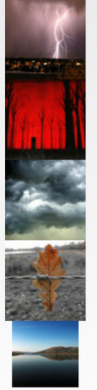


No pain at all

Submit

5 Please tap on the image that best represents your current pain level:

Worst pain imaginable



No pain at all

Submit

6 Please indicate your current pain level with the following seek bar:

Worst pain imaginable



No pain at all

Submit

7 Please indicate your current pain level by moving this bar:

Worst pain imaginable



No pain at all

Submit

8 Please indicate your current pain level with the following NRS:

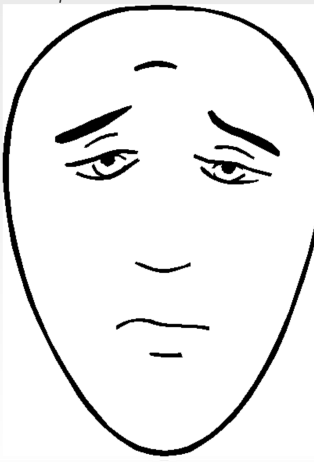
Worst pain imaginable

10
9
8
7
6
5
4
3
2
1
0

No pain at all

Submit

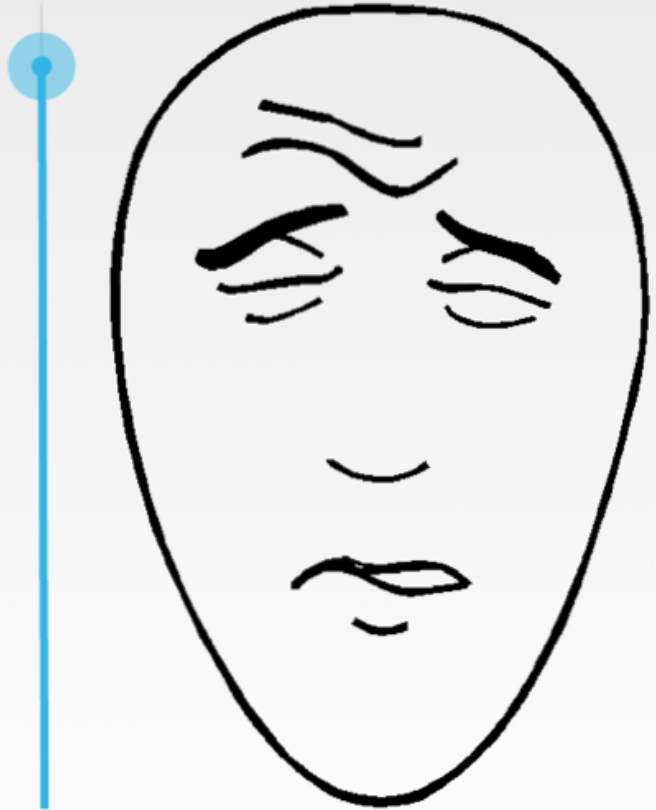
9 Please tap or swipe up/down to change the face such that it best represents your current pain level.



Submit

Please indicate your current pain level

Worst pain imaginable



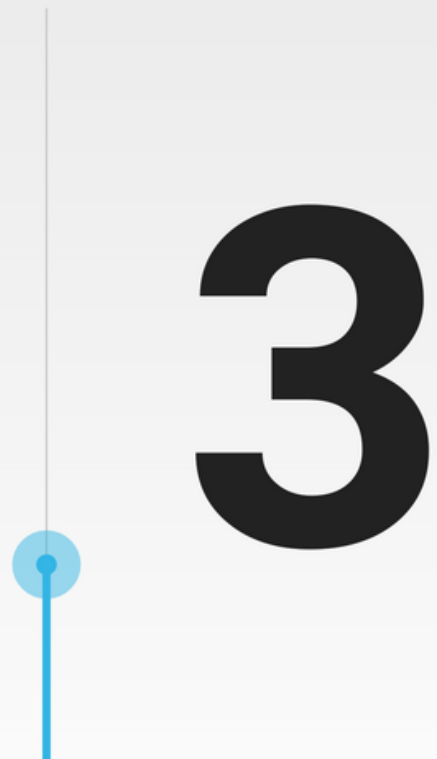
No pain at all

Submit

SAFESlider

Please indicate your current pain level

Worst pain imaginable



No pain at all

Submit

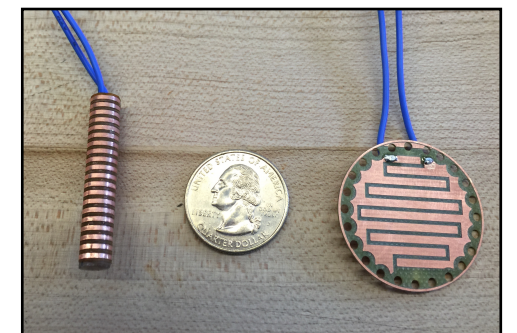
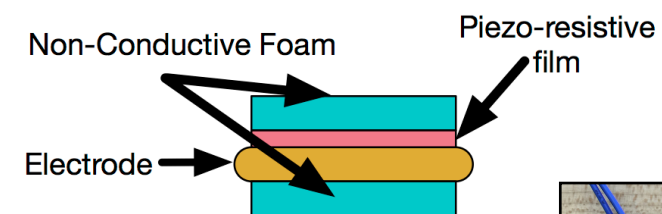
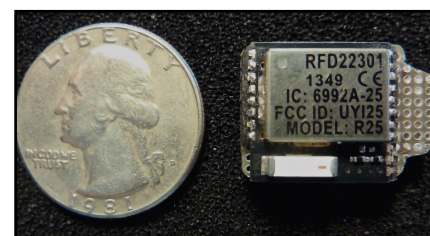
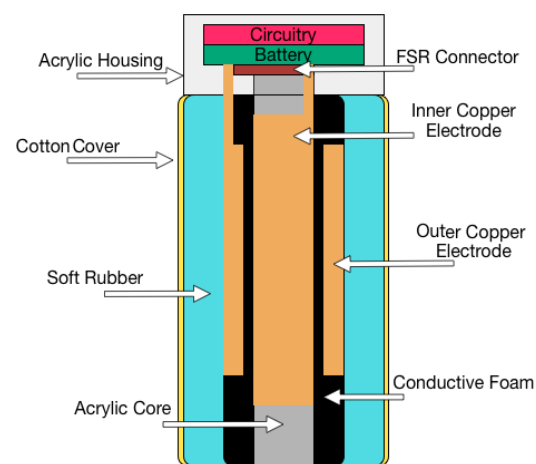
SuperVASNumbered

Deployment surfaces new constraints!

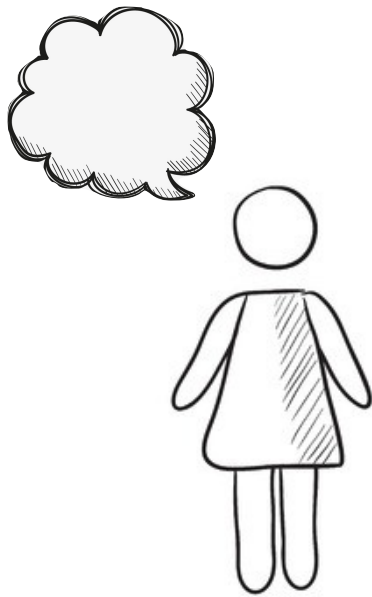
- ❑ Impractical or socially inappropriate to use a phone
- ❑ Time consuming to make a self-report
- ❑ **Age-specific** accessibility barriers
 - ❑ Low digital skills
 - ❑ Cognitive impairments
 - ❑ Functional limitations (vision, motor skills)

From screen to squeeze

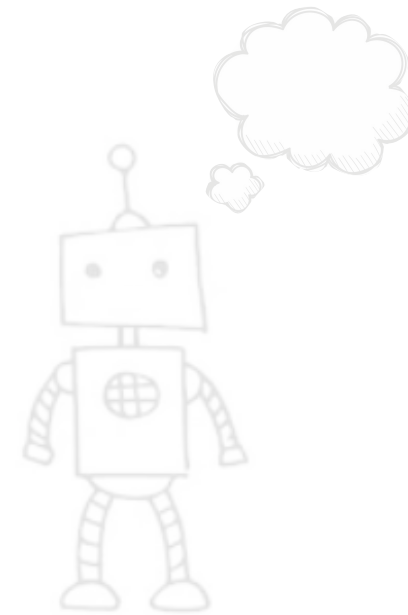
Tangible user interfaces to support natural, intuitive, discreet reporting



Manual & passive strategies



Subjective
self-report

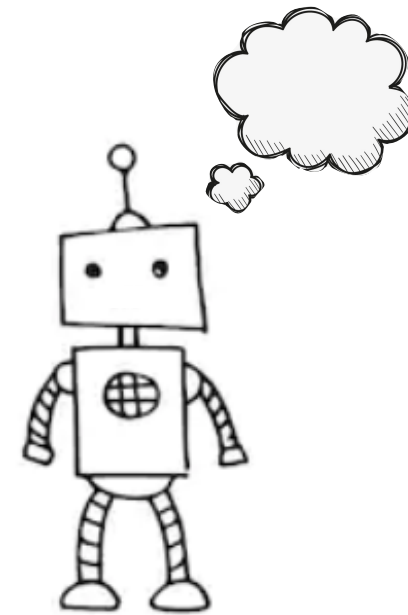


Automated
sensing

Manual & passive strategies

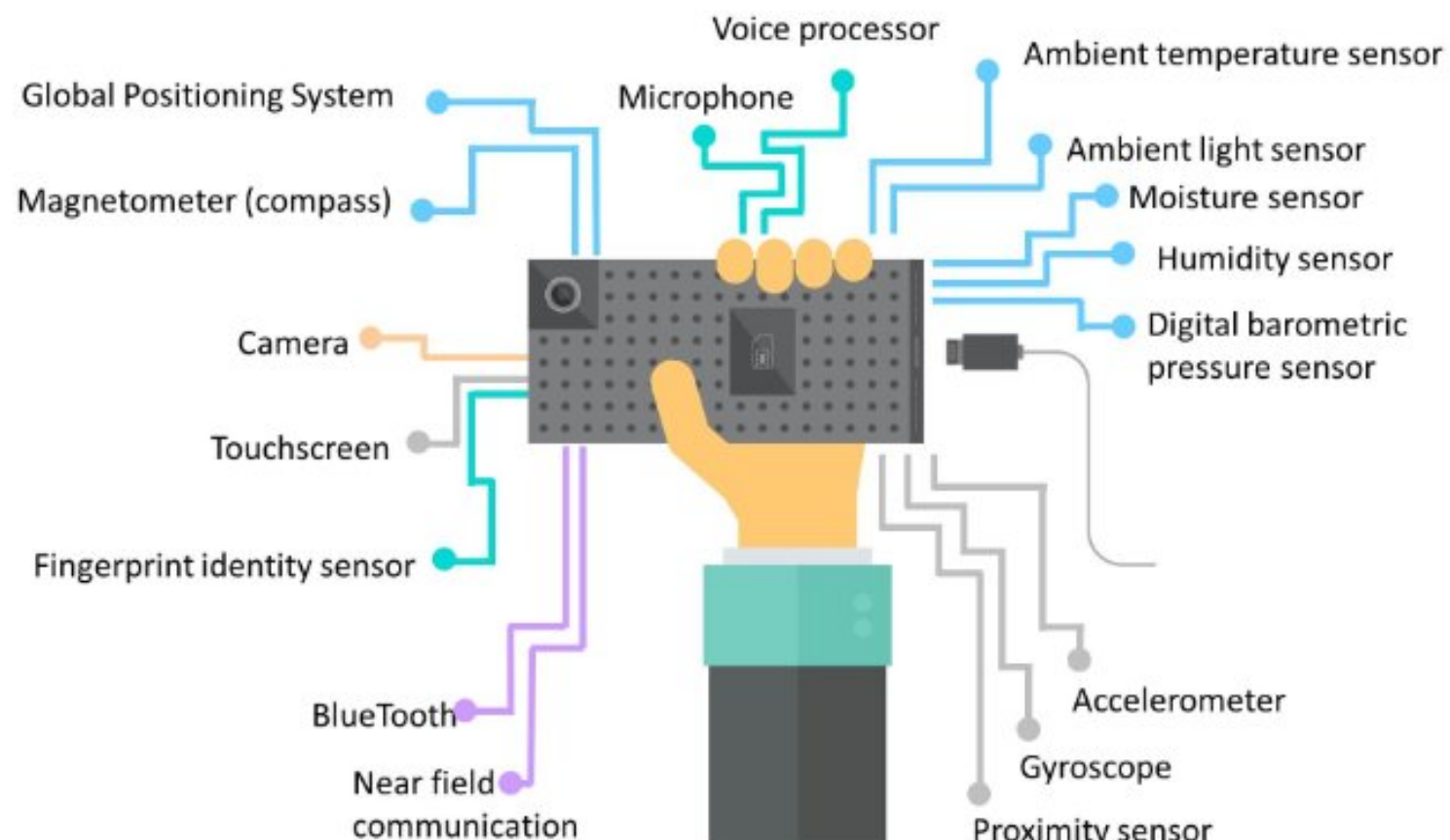
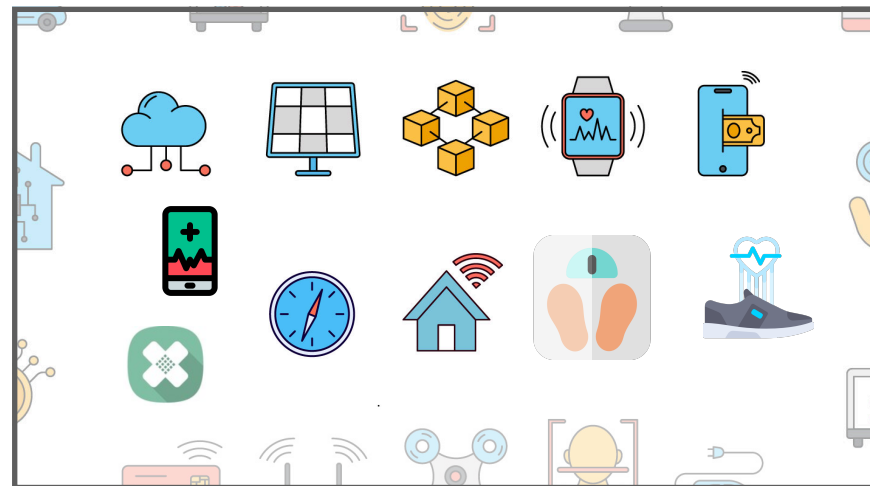


Subjective
self-report



Automated
sensing

“Passive sensing” captures behavioral and physiological data through sensors embedded in personal devices



Deriving digital biomarkers for aging use cases

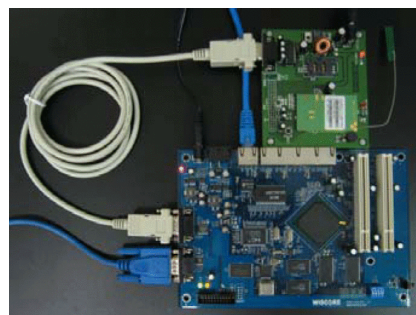
Sensors	Symptoms
Accelerometer, GPS	Mobility and frailty
Inertial sensors	Standing and balance
Microphone	Neurodegeneration
App usage logs	Cognitive declines

Sources: Castro 2015, Madhushri 2016, Piau 2019, Cormack 2019, Moro-Velazquez 2019, Gordon 2019

Wearables and on-body sensing



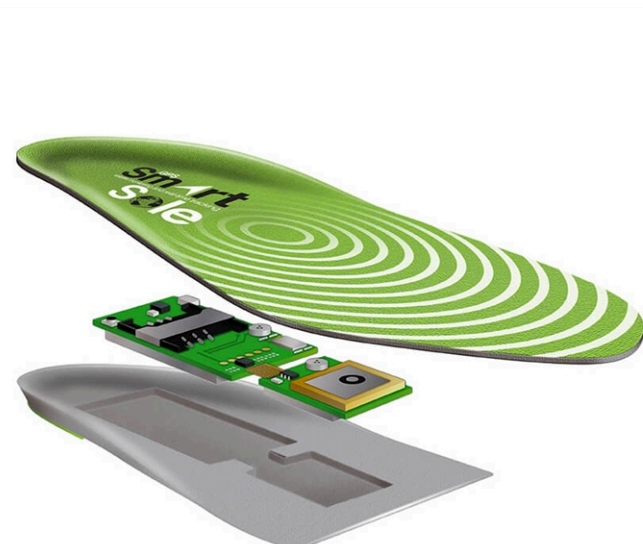
Motion impairments



Cardiac vital signs



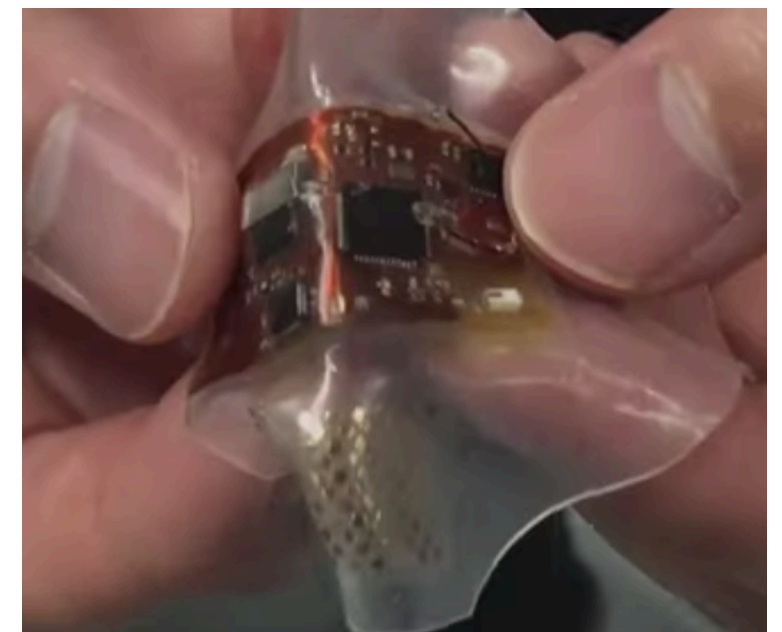
Attacks and falls



Whereabouts and safety

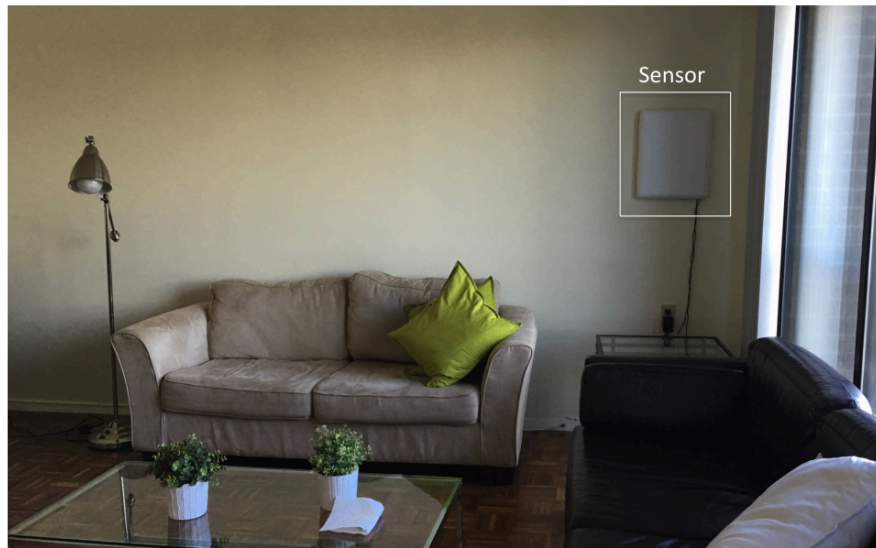


Heart & respiration rates, nap posture



ECG, heart rate, respiration, motion

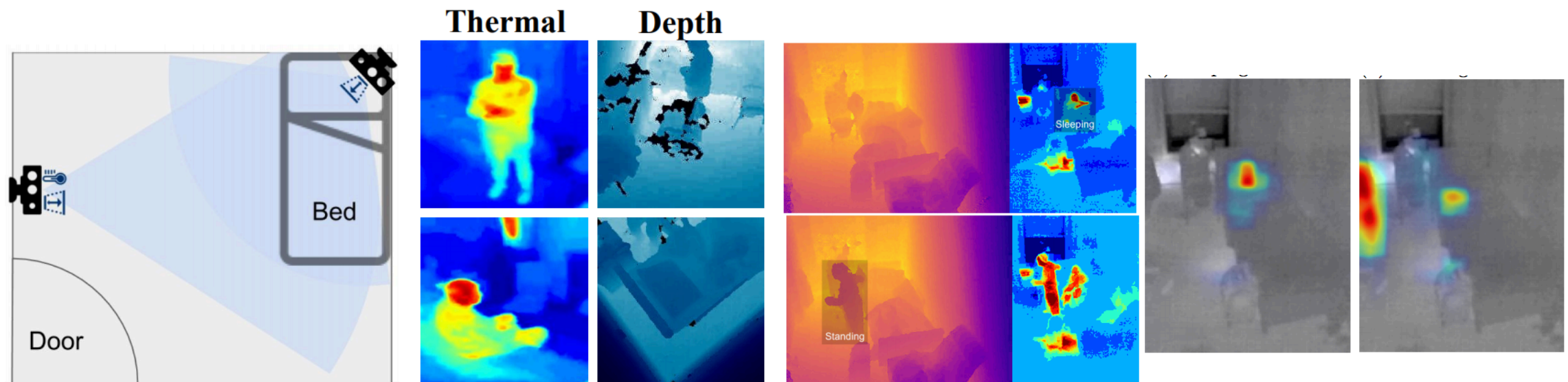
Contactless sensing and Internet of Things (IoT)



Gait velocity and stride



Insomnia and sleep



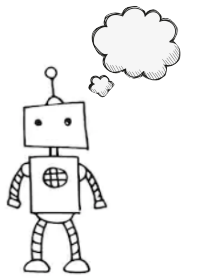
Acute incidents (fever, immobility) and routine monitoring (eating, sleeping)

Benefits, disadvantages, and trade-offs among data collection approaches



Manual tracking

- 👍 Sense of agency
- 👍 Mindful self-awareness
- 👍 Direct data control
- 👎 Tracking can be burdensome
- 👎 Limits on granularity of data a human can record
- 👎 Biases & inaccuracies of self-assessing status
- 👎 Negative reactivity

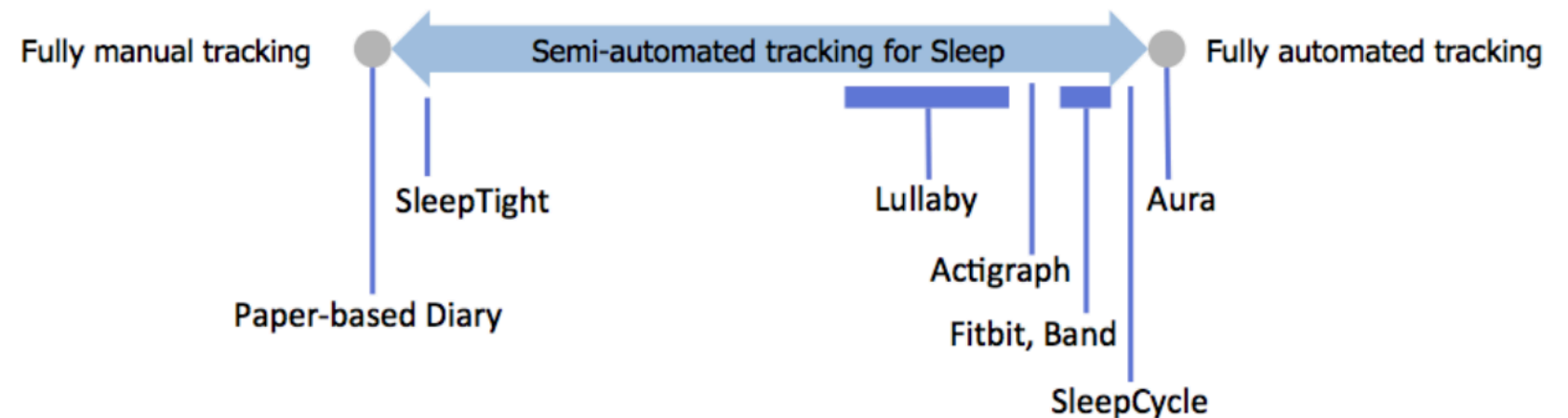


Passive Sensing

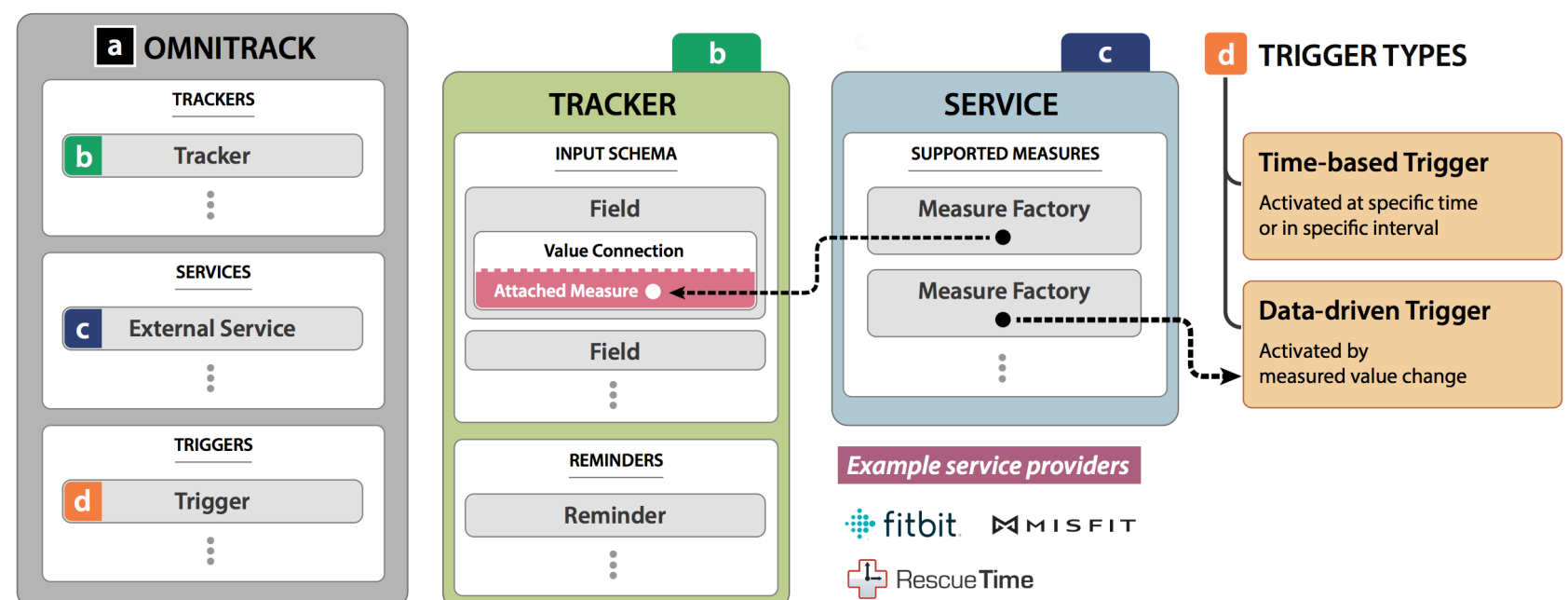
- 👍 Relieves tracking overhead
- 👍 Can capture data imperceptible to people and with more granularity
- 👍 “Objective” measurement
- 👎 Reduces personal awareness
- 👎 Can’t capture subjective experiences
- 👎 Inaccurate for some types of data
- 👎 Privacy invasive
- 👎 Security & storage of large volumes
- 👎 Uncomfortable to wear
- 👎 Data loss still an issue due to battery and forgetfulness to charge or wear

Hybrid data collection strategies

Sleep tracking examples according to Choe et al.'s (2017) semi-automated tracking framework:



Kim et al.'s (2017) OmniTrack implements an architecture based on such principles:



Beyond supporting care, mHealth can also drive basic science

- Studying diverse & large samples, in naturalistic settings, over longitudinal periods
- Academic efforts to develop general use, reusable, and extensible open mHealth platforms for research
 - AWARE, MyExperience, ohmage, Open mHealth Platform, Purple Robot
- But more research necessary to investigate and take steps to extend these platforms' accuracy, coverage, and appropriateness for **older adult** populations and adaptive aging applications

**Translating data to
insight, informatics, and
interventions**

Common informatics and intervention targets for aging applications



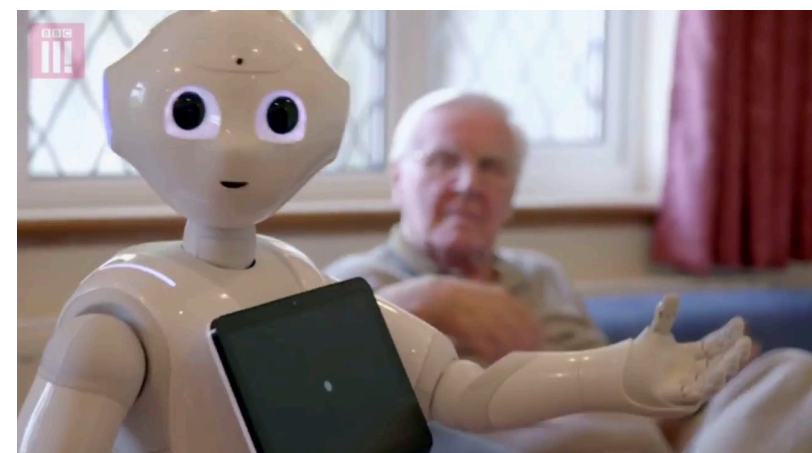
Ambient awareness for care networks and remote family



Reminders or nudges (medication, activity)



Intergenerational connectedness



Future visions

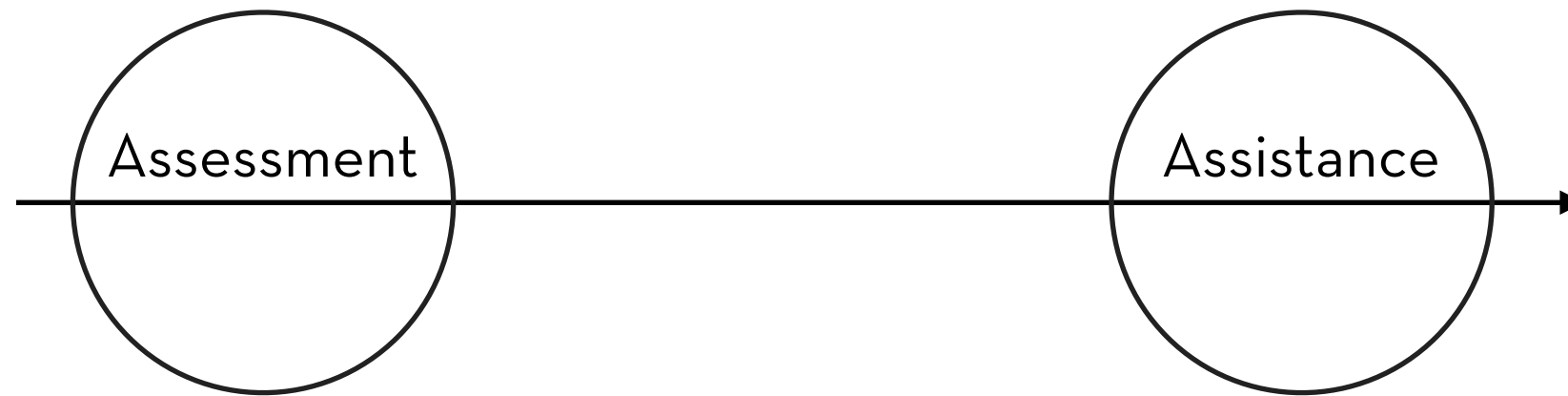
Concluding remarks & discussion

Design constraints and goals for adaptive aging mHealth tools

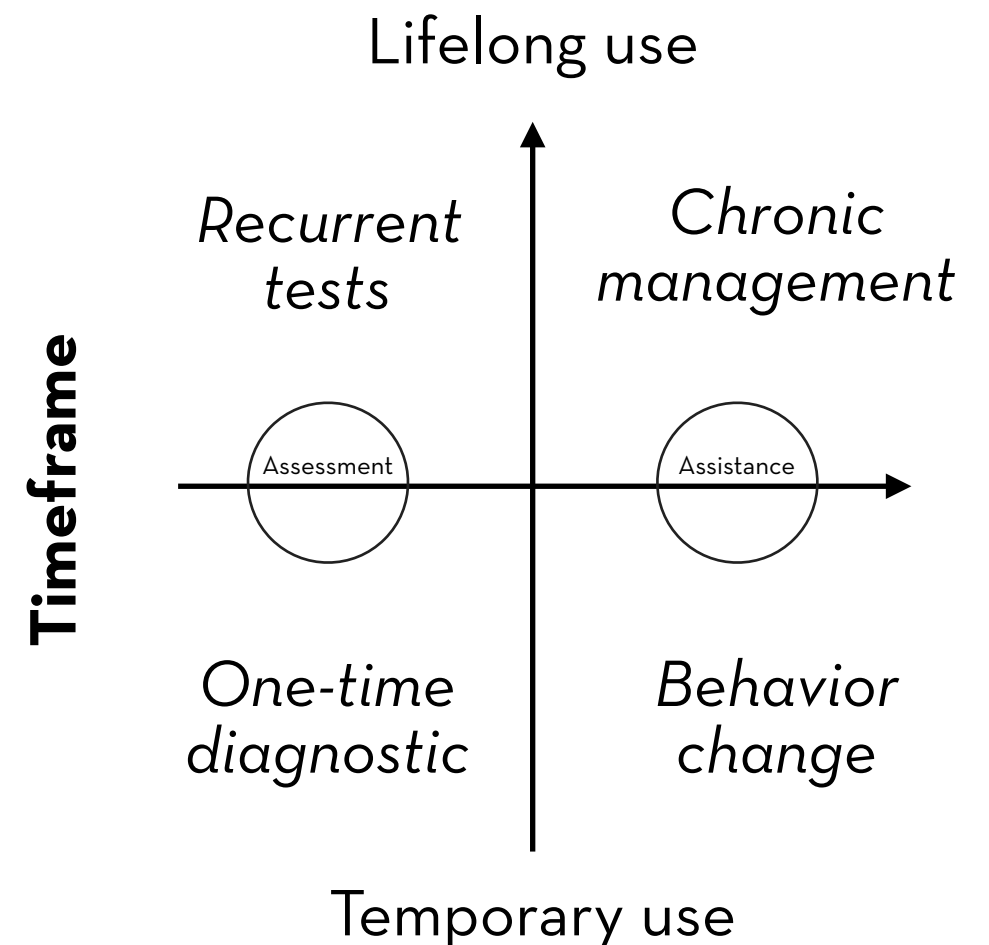
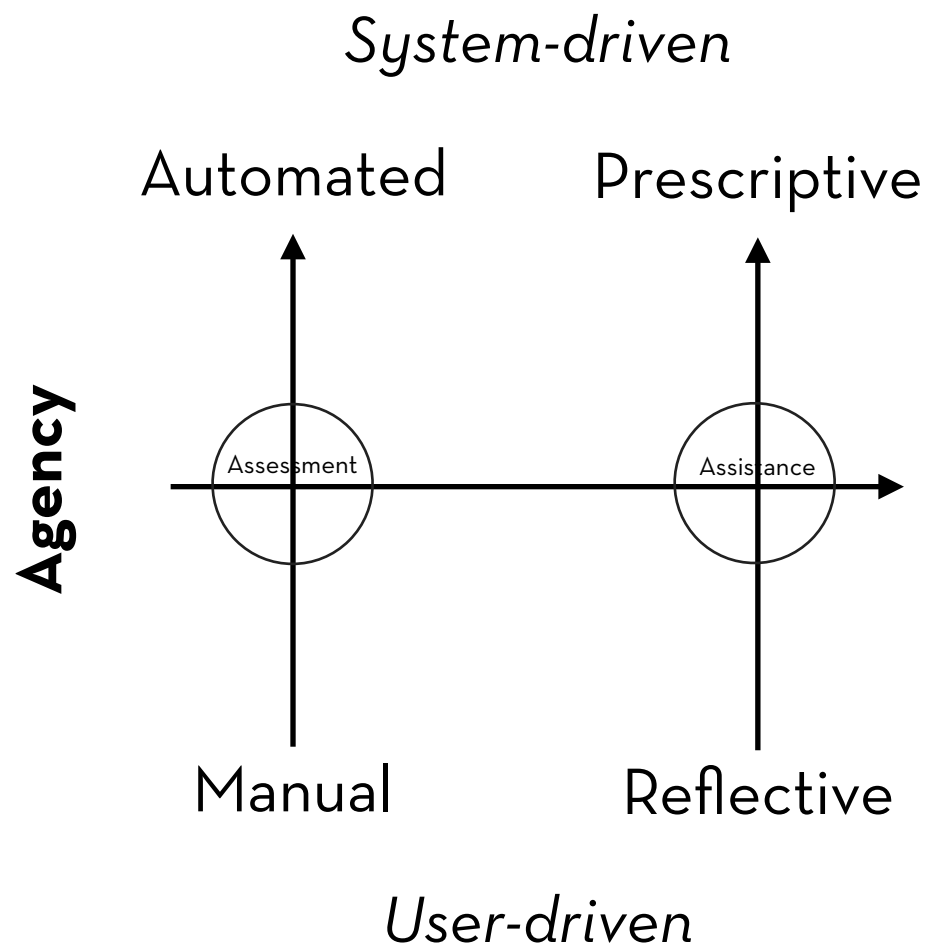
(requirements that research finds most mHealth tools are not designed to satisfy)

- Implementing **usability** features to make interfaces more accessible to older adults facing cognitive, motivational, or physical limitations
 - E.g., large touch-targets, readable fonts & sizes, high-contrast, simple interactions, low manipulability, enhanced and adaptive volume control
- Utilizing **interaction modalities** that are more intuitive and natural
 - E.g., older adults now account for over 1/3 of voice assistant users
- Minimizing info overload and delivering cognitively legible feedback
 - E.g., moving from heavily quantitative and text-based reporting to more **qualitative representations** of personal data

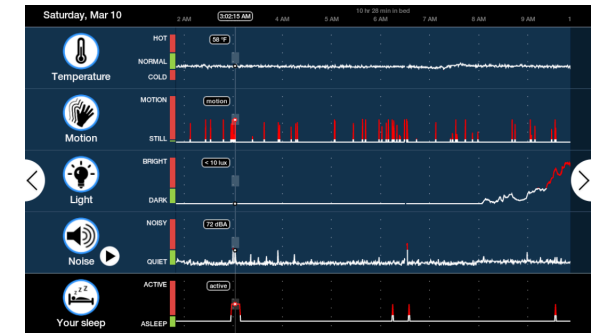
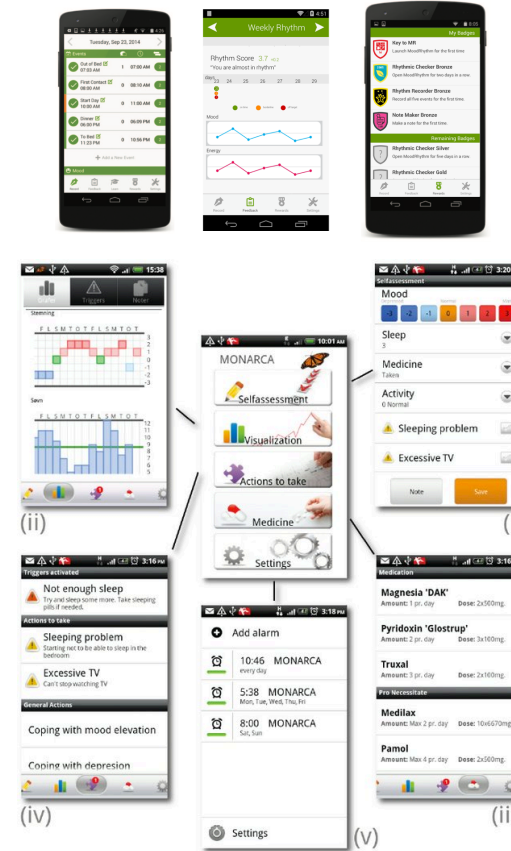
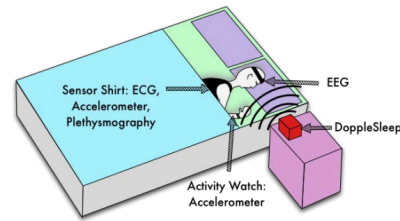
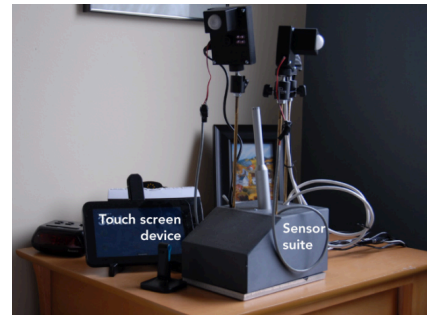
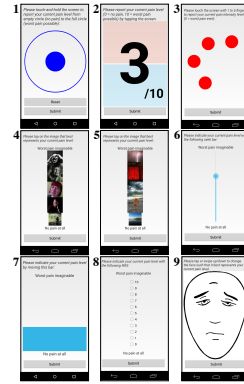
Conceptualizing design dimensions



(abstracted data pipeline)

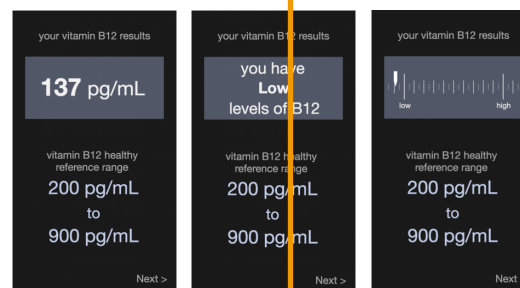
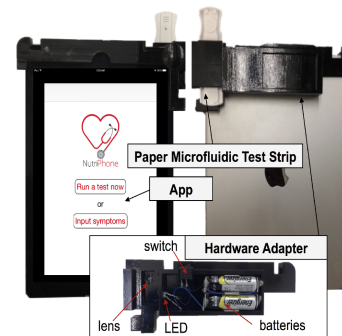
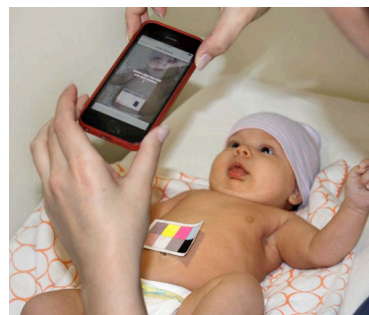


Long-term use



Assessment

Assistance



Temporary use

Ethical considerations for mHealth

- Responsible **management** of (potentially sensitive, stigmatic, and exploitable) collected data
- Older adults have raised general **privacy** concerns about health technology
 - Necessary to directly investigate older adults' privacy understanding & comfort levels
 - Develop usable mechanisms for communicating data preferences and controlling collected data (viewing, deleting, managing access)
 - Privacy-preserving sensing methods
- Regulation & **policy**
 - E.g., to guard against insurance companies setting rates based on a person's historical or predicted mHealth data
 - Formalized standards and approval procedures for new tools

Other future directions

- Need more common-format, interoperable, and reusable mHealth **platforms** vs. one-off applications
- Developing mHealth experiences and infrastructures to support the **social ecologies** of the aging process
- mHealth as a way to not only bridge **inequities** but uncover and understand them in the first place
- Designs that challenge ageist stereotypes and promote a framing of **flourishing** in later life

Thanks! Questions?

- Need more common-format, interoperable, and reusable mHealth **platforms** vs. one-off applications
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