Technologies for Heart and Mind: New Directions in Embedded Assessment

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ABSTRACT

Embedded assessment is a technology design strategy to drive preventive health care and early disease detection. This approach addresses barriers to early detection observed through ethnographic research. Health monitoring is integrated into everyday devices and then translated into personalized feedback that supports immediate wellness and long-term disease prevention. Three embedded assessment projects are described that involve close collaboration between the author (a clinical psychologist) and engineers in Intel's Digital Health Group. First is a mobile oximetry and feedback tool designed to facilitate safe exercise and thereby prevent escalation of heart failure. Second is a system of sensors and ambient displays to support social interaction and prevent cognitive impairment among older adults. Third is a mobile coaching system, responsive to physiological sensors, for people whose emotional reactivity poses risk for coronary artery disease. In these projects and ongoing work, granular biological and behavioral metrics are translated into psychologically meaningful feedback in order to motivate change.

INTRODUCTION

The vast majority of medical care remains focused on late stage illness, a bias that perpetuates the health care crisis in the U.S. and internationally. It is estimated that seventy-five percent of national health care costs in the U.S relate to the treatment of chronic diseases [1, 2]. Heart failure, for example, affects 5 million people and costs approximately $21 billion annually in the U.S. [3]. Although not classified as a chronic condition, Alzheimer's disease takes a similar toll: it now affects 4.5 million Americans, and is estimated to cost the U.S. $100 billion annually [4, 5]. To a large extent, the diseases that we treat almost exclusively in their late stages progress predictably, as do the costs of treatment. Symptoms that are difficult and costly to treat in late stages can be stabilized and sometimes reversed if addressed early. A growing body of literature suggests common vulnerabilities for heart failure, dementia, and a range of other diseases. These shared risk factors—negative affectivity, isolation, and weight gain—are ideal targets for preventive medicine.

Shifting more attention and resources to preventive care could certainly increase return on medical investment. But there are significant barriers: the close monitoring of risk factors required for preventive medicine is difficult for both clinicians and individuals. Clinicians lack sensitive tools to determine individual baselines of premorbid functioning and early signs of decline. Among individuals facing the prospect of a daunting disease, psychological dynamics such as denial and adaptive optimism delay acknowledgement of symptoms. People frequently overlook early signs and avoid clinical assessment, but at the same time eagerly adopt strategies to prevent future disease and compensate for their current limitations [6].

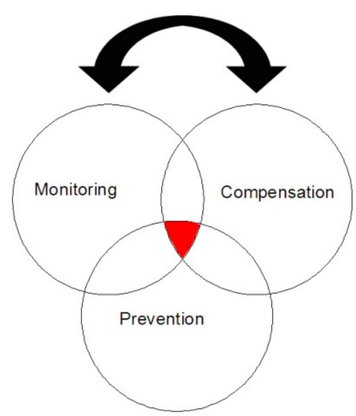


Figure 1: Embedded Assessment: Closing the loop

This approach links health monitoring with tailored feedback to help individuals compensate for current limitations and prevent disease.

Embedded assessment emerged as a design resolution to the conflict between the need for early detection and significant obstacles to health monitoring. In this approach, continuous assessment is integrated into an individual's routines and translated into supportive, tailored feedback. The feedback helps the person compensate for current limitations and prevent future disease. The closed loop between monitoring and compensation ensures that individuals receive the appropriate level of support. Conversely, trending of users' responses to graduated cues reveals variability in how much help is required at different times—data that can help with early detection. If embedded assessment technologies are adopted in midlife for performance optimization and disease prevention, they can identify individual baselines and early indicators of health decline (see Figures 1 and 2 and [6]).

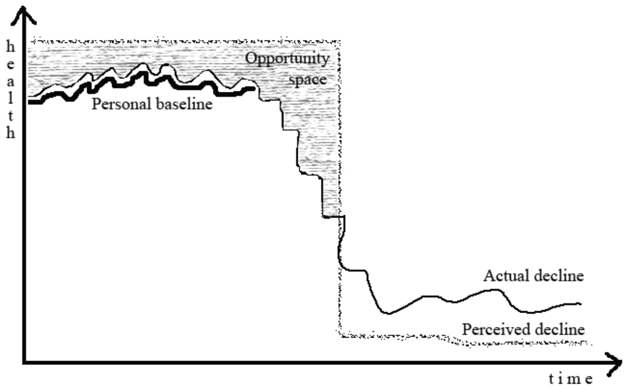


Figure 2: Opportunities for early detection

Diagnosis and treatment are delayed by limitations in clinical assessment and psychological dynamics such as denial. Embedded assessment determines personal baselines and early disease indicators.

In this paper I examine three means for embedded assessment to assist with management and prevention of disease. I review three research prototypes that vary in preventive reach (from acute symptom management to risk reduction far in advance of illness), the time intervals for monitoring, and the degree to which monitored data are translated into feedback. The first, a mobile oximetry device, is intended to reduce acute risks associated with exercise in heart failure patients. It monitors cardiovascular exertion levels over short time intervals and reflects them in a relatively straightforward manner. The second, a social health platform for older adults, monitors and facilitates behaviors with preventive value over slightly longer intervals (from days to months versus minutes). The feedback is translated from a quantitative index of social interactions into metaphorical visualizations of interpersonal engagement. The last, a mobile feedback system for emotional self-regulation and preventive cardiology, is the most far reaching of these projects. It is intended to be used far in advance of disease onset, and it translates physiological data into psychological interventions.

EMBEDDED ASSESSMENT EXAMPLES:

Project 1: Mobile Oximetry

Motivation in Ethnography

This innovation was inspired by struggles of patients with heart failure. Heart failure is one of the leading causes of death in the U.S and is very costly and difficult to treat in its late stages. Life is seriously restricted for these patients, who must follow a strict plan of diet, exercise, and medications. Even small deviations, for example, in salt intake or exertion, can result in a sudden inability to breathe. Heart failure patients are known to fill emergency rooms for this reason: these visits are frightening, extremely costly, and largely avoidable.

Ethnographic interviews with patients and clinicians revealed barriers to this critical regime of medication, diet, and exercise. Here I focus on the theme of maladaptive risk aversion as a barrier to exercise. This risk aversion involves a fear-driven collusion between clinicians and patients that contradicts explicit guidelines. Patients are formally advised to exercise, but informally discouraged from doing so. The implicit message they receive from clinicians, especially when a condition worsens, is to tread very carefully once outside the safety of the clinician's office. Patients commonly receive an "exercise prescription" for a physical rehabilitation clinic, but this setting is impractical and undesirable for most patients. As a result, patients frequently become tethered to their homes and restricted from the physical and social stimulation that is critical to their long-term health.

Fear of overexertion and other barriers to exercise among heart failure patients are illustrated in the case examples below:

- A woman in her early 90's calculated that she can typically walk 50 steps. Her trip to get the mail is just within this range, and so she often hesitates to venture out: "I might not be able to make it back from the mailbox."
- A woman in her 50's dislikes gym exercise but enjoys catering for her church. This volunteer work is physically, socially, and spiritually invigorating. But after helping out with the last church dinner she ended up in the emergency room. Over the years, she's had many frightening hospital visits. She wants to feel productive and remain engaged with her community, but doesn't know how to avoid over-extending herself.
- I overhear a nurse encourage her patient, a 38 year-old woman who moved to the U.S. from Jamaica, to enroll in the hospital's physical rehabilitation clinic, "It's there for you … and it's free... why don't you try it?" The patient responds that she didn't know about the clinic; according to the nurse they've had this conversation several times. Later the patient tells me "I'd like to dance or do yoga… not be wired up to a treadmill. … And that clinic is really far – a $40 taxi ride from here."

These patients want supportive reassurance for their exercise and other activities, in the context of their daily environments. They need to know, at the moment of activity, whether or not they are within safe parameters of exertion. Over longer time periods, they need motivational coaching to illustrate progress towards long-term goals. Patients expressed helplessness about exercising and losing weight, even if refusal to do so eliminated chances of a heart transplant or significantly worsened prognosis in a more general way. These observations inspired the prototype below which provides immediate feedback to help people modulate exertion; and a longitudinal view to reinforce progress towards health goals. The mobile wireless form factor allows people to move free of wires, in places that are convenient.

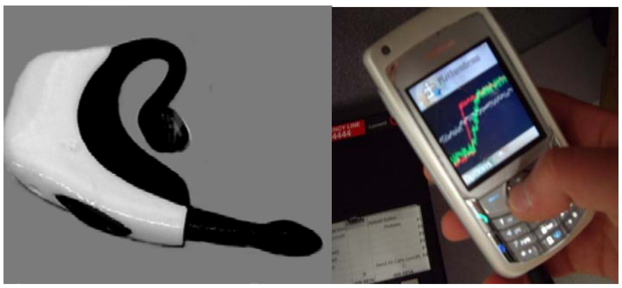


Figure 3: Oximeter earpiece and mobile feedback

Continuous, untethered monitoring, coupled with mobile feedback helps cardiovascular patients modulate exertion and benefit from exercise.

The Research Prototype

The prototype (shown in Figure 3) allows continuous, untethered monitoring of cardiovascular exertion and real-time feedback on a mobile device. Oximetry, a measure of blood oxygenation, is unplugged from a normally cumbersome system and embedded into the wireless earpiece. These data are plotted against accelerometry data to indicate the relationship between activity and cardiovascular distress. The screen displays a short-term view of current exertion levels and a longitudinal view to reinforce the patient's progress towards exercising and fitness goals.

Components of Embedded Assessment

Monitoring. Oximetry and accelerometry are embedded into a wireless earpiece of a mobile phone to allow for continuously monitoring of cardiovascular stress and trending of exertion relative to activity levels.

Compensation. The phone displays real-time feedback to help the patient monitor cardiovascular stress. The feedback compensates for an impaired regulatory system. The snapshot view is most useful for modulating exertion (e.g., resting); the longitudinal view visualizes progress towards fitness goals that might not be immediately apparent, and thereby motivates continued exercise.

Prevention. This system is intended to prevent the progression of heart failure and other forms of cardiovascular illness by helping patients to stay safely physically active. Real-time alerts about over-exertion may reduce dangerous incidents.

Future development will concentrate on the feedback displays for this system. One challenge is to encourage self-awareness of both exertion and positive feelings from increased exercise. The feedback should foster, not replace, autonomous motivation and self-regulation. Other critical questions concern the representation of cardiovascular health in ways that are psychologically compelling and culturally resonant.

Project 2: Solar Displays for Social Health

Motivation in Ethnography and Previous Research

Social engagement has profound health benefits, protecting against illnesses from the common cold to dementia [7, 8]. Our ethnographic inquiry highlighted barriers to social engagement in later life [10]. With retirement, many people lose opportunities for spontaneous contact as well as visibility of others' availability. Concerned about imposing on others or being rejected, many drift into isolation. These situational shifts, along with cognitive changes, such as difficulty recalling names or following rapid conversation, make many feel helpless about loneliness. As one formerly very social man put it "loneliness is a part of old age and there ain't a damn thing you can do about it."

We also noted significant variability in the way older adults described their experiences of loneliness. Current measures and interventions underestimate this variability and rely on characterological rather than situational explanations for differences in social engagement. But our interviews suggest that, like blood pressure or glucose levels, loneliness varies by the moment and therefore requires adaptive solutions.

These themes of helplessness and variability are illustrated in examples below:

- After the death of her husband, an 82-year-old woman moved across country to be near her daughter. She left behind a network of friends. She is socially gracious and very charming but uncomfortable initiating contact. She loves seeing family, especially her grandchildren, but feared imposing. A history of depression makes isolation a particularly serious risk.
- A 77-year-old divorced woman enjoys casual interaction with neighbors, choir practice, and creative writing during the week but dreads the weekends: "I just wish I could make them disappear." She retained an expectation that weekends should be spent with family and suffered chronic

disappointment because her children were typically unavailable on weekends.

- An extremely bright and extroverted 91-year-old woman relocated to live near her son following an injury. She now struggles with quiet evenings in a retirement community. She fills her days with group activities and enjoys the weekends she spends with her son's family, but complained that, in the evenings "It's like a morgue around here."

Psychological research has demonstrated the benefits of mindfulness, or awareness of change. When people recognize fluctuations in negative circumstances, particularly their own ability to bring about positive change, they feel less helpless [9]. In this research, we tried to foster elders' social self-efficacy and empowerment by highlighting the dynamic qualities of social interaction.

The Research Prototype

We developed a platform of sensors and feedback displays to measure and encourage social engagement, for the prevention of cognitive decline. In the primary feedback display (Figure 4), friends and family rotate around the elder—planets which can be pulled in by a phone call or visit. This use of social networks as health feedback displays is described in [10].

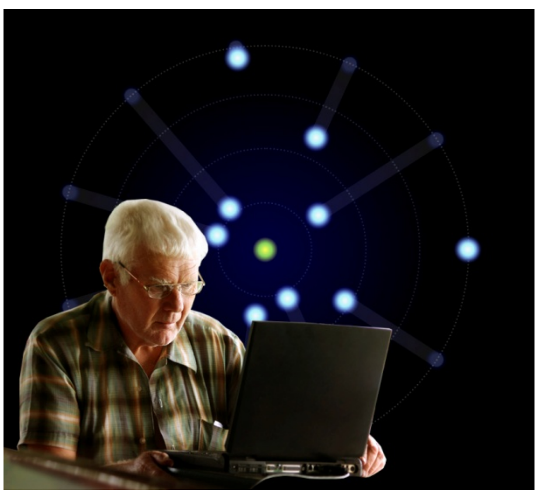


Figure 4: Solar display of social activity

The elder, depicted as the sun in the center of the display, is surrounded by planetary representations of friends and family. Social interaction, measured by sensors, draws planets closer to the center.

The Components of Embedded Assessment

Monitoring. A sensor network and online journal allowed continuous measurement of phone activity and other social interaction over several months. We first determined a baseline of social interaction (by monitoring only) and then measured changes in social interaction associated with the introduction of feedback displays.

Compensation. To encourage and reinforce social efforts, the displays provided real-time feedback of interactions with friends and family. It was important that the displays be intuitive and nonstigmatizing. They included the solar view shown in Figure 4, longitudinal graphs, visual cues of callers' names and faces, and a lamp that signaled the availability of a family member. Feedback was intended to help people compensate for isolated lifestyles and for cognitive changes in recall and processing of social information.

Prevention. This system was intended to protect against onset and progression of cognitive decline, by motivating social outreach and mitigating feelings of loneliness.

Responses to Solar Displays

A three month long in-home pilot study indicated that the feedback displays were valued by elders and their caregivers (see [10] for fuller description). We observed subtle and overt increases in social engagement. These behavioral changes not only improved the quality of life for elders and families, but they also set in motion a style of interacting that may protect against a range of illnesses in later life.

Revisiting case examples above:

- The 82-year-old woman who didn't want to burden her family started initiating plans, especially with her grandchildren. She also began volunteering as a teacher's aid for first-grade students. This activity was very gratifying for her, in part because of the positive impact she had on others. Her daughter exclaimed, "The kids love her … she's in the yearbook and they've asked her to continue helping the same class next year."
- The 77-year-old woman who dreaded the weekends became more involved with friends. For example, she started seeing some members of her choir group outside formal practice sessions. These outings and those with other friends shifted her attention away from the unavailability of her children.
- The 91-year-old woman who spends weekends with her son remains very close with her family. But she also started reaching out to peers in the retirement community with a new level of interest. She even invited some neighbors into her apartment.

Observations from this study have implications for the model of embedded assessment. First, the feedback displays raised participants' enthusiasm for monitoring technologies that they initially experienced as intrusive and burdensome. Their enjoyment of the displays appeared to generalize to the monitoring: several participants even started to speak of the online journaling as a hobby. This observation provides support for the premise in embedded assessment that feedback will motivate monitoring. Second, elders and caregivers recognized opportunities in the feedback displays to catch early trends of isolation. This eagerness to catch early indicators, central to embedded assessment, most likely occurred because the visual displays invited people to objectively examine and discuss topics that were previously avoided or overlooked. Finally, we observed that the adult children who participated in the study as caregivers used the displays as an opportunity to reflect upon their own lives and set priorities pertaining to their health, professional pursuits, hobbies, and relationships. This finding supports the idea that embedded assessment technologies should be adopted in midlife to support early detection: tools used to help an elderly parent can simultaneously offer services to help a caregiver manage his or her own life. Baseline data can be gathered from implicit variables, such as the caregiver's typing speed or voice quality, as well as explicit entries in care-giving and self-health applications.

Project 3: Mobile Heart Health

Motivation in Ethnography and Previous Research

This project is grounded in preventive cardiology and ethnographic research on interpersonal conflict. Cardiovascular health is increasingly understood as the accumulation of behaviors, perceptions, and emotional reactions throughout life. This lifestyle view is reflected in etiological metaphors for cardiovascular disease; even the explanation of heart failure is shifting from the dichotomous model of a "broken pump" to the process of "progressive remodeling." Cardiovascular disease progression is influenced by an array of stressors, including hostility or proneness to interpersonal conflict (reviewed in [11]). The cumulative stress of repeated interpersonal conflicts, like the damage incurred by insufficient sleep, poor nutrition, and inactivity, leads to a prolonged deregulation of the autonomic nervous system and what is termed "allostatic load" [12].

Psychological interventions can help people modulate interpersonal stress and its consequences. Cognitive behavioral therapy can have dramatic effects by training people in "emotional regulation" or what mindfulness practitioners call "catching the flicker before the flame." Patients learn to critically evaluate the automatic thoughts and maladaptive interpretations that generate negative emotions and reactions. To address a highly conflictual style, this therapy emphasizes the tendency to perceive irritating situations as intolerable and unjust. Through self-awareness, patients learn to modulate their emotional and physical reactions to stress. The therapy also emphasizes alignment of behaviors with goals, assertive problem solving, and relaxation exercises [13].

The biggest limitations in behavioral medicine and psychotherapy are scalability: few people have access to good mental health care. The continued stigma associated with psychotherapy adds another barrier to those who could benefit. Furthermore, interventions are generally not available in the moments of greatest need. Therapy appointments are scheduled, stressful interactions are not.

Ethnographic interviews illuminated contexts for interpersonal stress, physical symptoms associated with conflict, and personally tailored coping strategies. Below are several examples that inspired concept development.

- Irritated by loud fellow travelers on the subway, a woman sheltered herself with mobile tools "I shifted my iPod* to something more soothing, opened my book and locked myself in a little cocoon."
- "Sometimes I'll lock myself in the bathroom (just to take a breath)… my kids are pounding on the door." This self-described "married single mom" sets her phone display to read "calm now." (Figure 5).

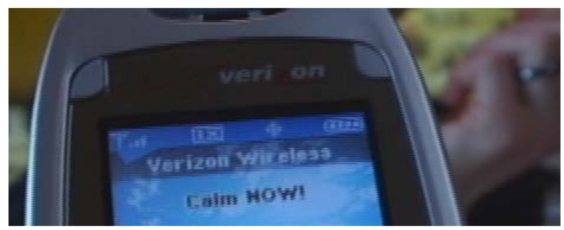


Figure 5: A woman reprograms her mobile phone display "I look at it, I breathe and I get calm."

- A man invents reasons to leave irritating work meetings, "I'll say I have to go get something at my desk…just to get out of a meeting for a bit... sometimes I half convince myself that this is true… it's a really internalized strategy I've developed to step away."

As an ethnographer and a clinician, I was impressed by the immediate effectiveness of these strategies. In contrast to common therapeutic techniques, they are highly contextualized, personalized, and almost instantaneous. They point to exciting opportunities for mobile therapies to enhance and expedite clinical medicine.

The Research Prototype

Continuous monitoring of stress is coupled with timely mobile feedback (see Figure 6). Mobile interventions are prompted by cardiovascular, contextual, and subjective stress indicators. The interventions are inspired by cognitive behavioral therapy and mindfulness practices and they are translated to mobile interfaces. The intent is to provide support, when and where it is most needed, to help alleviate emotional distress and limit cumulative risk of cardiovascular disease.

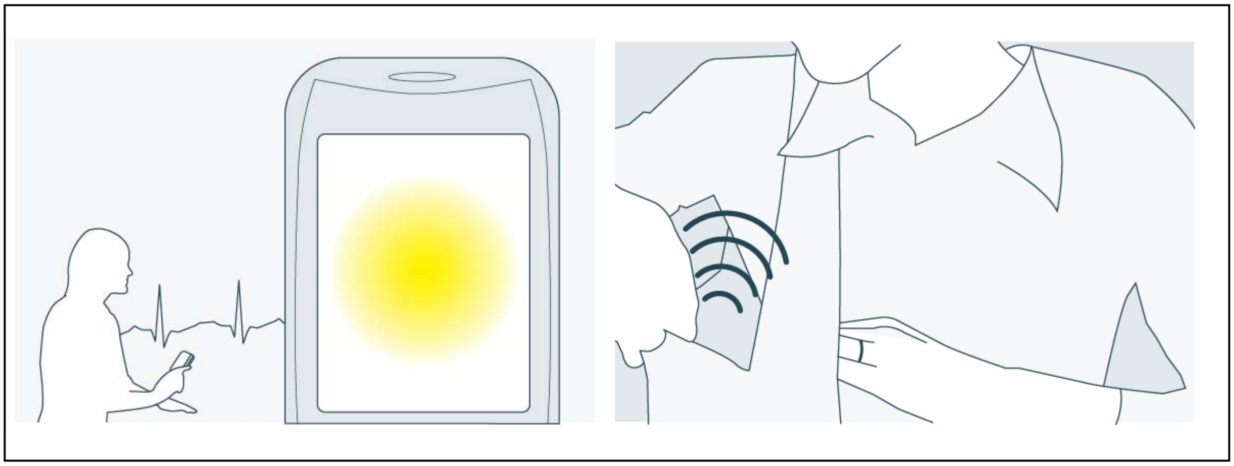


Figure 6: Mobile heart health

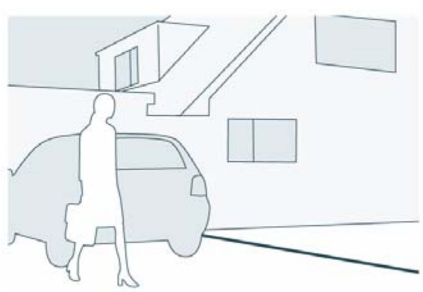
Mobile therapy is triggered by physiological, contextual and self-reported stress indicators. This woman's phone provides an "exit strategy"–a call away from a conflict–after detection of cardiovascular stress. The goal is to improve emotional regulation and reduce the risk of cardiovascular disease.

Components of Embedded Assessment

Monitoring. Wireless monitoring of physiological, contextual, and self-reported stress occurs via worn and environmental sensors and phone applications. Physiological sensing occurs via a chest-worn sensor that tracks heart rate characteristics, temperature, and movement. Contextual indicators are measured with location beacons and a calendar system. Self monitoring occurs via a touch screen translation of a mood questionnaire [14], and a "panic button."

Below Figures: In addition to physiological sensors, location beacons, "mood mapping', and a "panic button" also monitor stress indicators.

7a: Bluetooth and iMote detect stressful transitions between home and work, and prompt contextually appropriate therapies.



7b: Mood Mapping allows touch screen indication of emotional valence and intensity.

7c. Pressing the "panic button" expresses fiery rage and initiates the "exit strategy" intervention.

Compensation. Feedback based on cognitive therapy protocols [13] to encourage reinterpretation of negative thoughts, physiological relaxation and behavioral change is triggered by the stress indicators above. The feedback is adapted to the mobile form factor and personalized. Examples include animated breathing exercises, and provocative questions, music and imagery.

Below Figures: Reference to cognitive therapy [13].

8a. Breathing exercises offer guided relaxation

8b. Positive images are beamed before stressful encounters to inoculate against conflict

8c. Invitation to reappraise automatic thoughts

Prevention. This system is intended to reduce the risk of cardiovascular disease by improving emotional regulation and limiting the cumulative toll of interpersonal stress.

The mobile heart health system illustrates some of the value propositions and capabilities of embedded assessment that could inform future products. In upcoming field studies, we will examine how people relate to this feedback system over time, how they integrate it with their other healing and communication practices, and most importantly, how it affects their emotional and physical health.

CONCLUSION

Embedded assessment offers a basic strategy for addressing a broad range of health issues, across stages of illness and at different points in the lifespan. The prototypes shared in this paper illustrate key capabilities of this approach: continuous sensing of objective and subjective health indicators, intuitive feedback offered when and where it is most needed, and facilitation of activities with preventive value. Future products using this approach will most likely include a more comprehensive set of sensing and feedback applications to address a range of health concerns. For example, the cardiovascular sensing and mood reporting in mobile heart health project would be logically combined with the interpersonal measures from the social health platform. The addition of other noninvasive measures (e.g., of glucose and hormonal levels) would allow such systems to adapt to the changing health needs that individuals experience at different points in their lives.

Significant design advances are necessary to develop compelling products from the exploratory prototypes discussed in this paper. Hardware configurations must of course extend from the standalone PC to a range of mobile and wearable interfaces. These systems will require more sensitivity to both geographic and social contexts. Computing intensive solutions will be required to interpret continuous streams of behavioral and biological data gathered by peripherals.

Perhaps even greater challenges lie in interaction design. We need to display health information in ways that mirror the mental schemas that people use to make sense of health concerns and the rest of their lives. That is, they need to reflect not isolated biological metrics but complex interplays of emotion, cognition, social interaction, and physiology. In addition, far more intuitive interfaces are required for collecting and reflecting health data. Input modalities, ranging from passive physiological sensing to gesturing, will depend on individual preference and contexts. Similar differences apply for feedback: a succinct text message might be ideal in some situations, but in others, musical feedback or a physical nudge will be more effective. Research is needed to develop these basic interaction modalities and to determine their adaptation to individuals, context, and moment-to-moment variability in health status. Advances in data visualization and interaction design will increase the odds that technologies will stick. Ultimately we want to develop objects that people not only use, but love, ones that invite close attachment as individuals initiate and maintain the often difficult changes required to improve their health.

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