Biofeedback Revisited: Dynamic Displays to Improve Health Trajectories

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Abstract. This paper outlines an approach for prospective health technologies: systems that inspire changes in midlife to prevent onset and progression of disease. Motivational hooks related to wellness, appearance and relationship satisfaction are aligned with long term disease risks and supported through dynamic feedback displays. Wireless sensor networks, inferencing, ambient displays and mobile interfaces are explored to carry biofeedback into everyday life. Several examples of display concepts – created to facilitate self-regulation of social engagement, weight, physical exertion and stress reactivity – illustrate this approach. Future work will explore mind-body relationships and extend from informational displays to experiential feedback.

Increasing life spans and constrained medical resources have motivated a wide range of technologies to increase satisfaction and independence in later life. These developments, which leverage sensor networks and ambient displays, range from contextualized prompts for grooming, medicating and eating and to cute robotic seals that provide soothing companionship [1,2,3]. Such technologies provide much needed support to people coping with chronic diseases and other age related challenges. But a greater emphasis on prevention is needed to disrupt our overwhelmed health care system, which still focuses the vast majority of resources on acute care for the severely ill. It is estimated that seventy-five percent of national health care costs in the US, an annual total of 1 trillion, relate to the treatment of chronic diseases [4]. The chronic diseases that we now treat almost exclusively in their late stages progress slowly and 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. Preventive medicine is slowly gaining momentum, and some particularly compelling approaches, such as Snyderman's "prospective care" model, illuminate how return on investiment could be increased by redistributing spending [4].

Health technologies, like the medical system, would have greater impact if more thought was given to prevention. In this paper, I propose a design strategy for "prospective health technologies" – aimed at improving health trajectories of people currently in midlife. The crux of this approach is driving behavioral change that will bring these individuals immediate benefit while lowering their long term health risks. Key elements of this approach are described, followed by examples concepts, and future directions.

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1 Working Backwards: Mapping Common Sources

It is now popular knowledge that many chronic diseases reflect behaviors and lifestyle choices throughout life. Genetic vulnerability and environmental factors should not be overlooked, but health status at any given moment can be seen in large part as the sum of actions and reactions throughout life. New models of stress, such as Bruce McEwen's "allostatic load," illustrate the cumulative damage imposed by extended autonomic imbalance [5]. Immediate and long term health are influenced by moment to moment behaviors ranging from deliberate decisions about eating, exercising, sleeping, and socializing, to ingrained styles of regulating mood and coping with stressors.

To illustrate this approach for prospective technologies, I've heuristically sketched pathways for two very significant health conditions that typically manifest in late life – heart failure and dementia (Figure 1). The links in these pathways are not demonstrated causal relationships, but correlations that have emerged from longitudinal and retrospective studies. I highlight these two conditions because of their prevalence, costs and detriment to quality of life. Heart failure affects 5 million and costs approximately $25 billion annually in the U.S. [6]. Dementia is one of the greatest risks to independent living and is rising rapidly with the aging population. Alzheimer's disease alone now affects 4.5 million Americans, and is estimated to cost the U.S. 100 billion annually [7,8]. A growing body of literature suggests key shared vulnerabilities for heart failure and dementia: negative affectivity, stress, social isolation, and weight gain. The trajectory towards heart failure commonly proceeds from weight gain to diabetes and then coronary artery disease. Depression may moderate this progression [9]. The trajectory towards dementia appears hastened by depression, social isolation, inactivity, poor dietary choices and cardiovascular disease [7,8,10,11,12]. Health technologies can have a great impact by focusing on the commonalities in these pathways, specifically weight gain, negative affectivity, and social isolation.

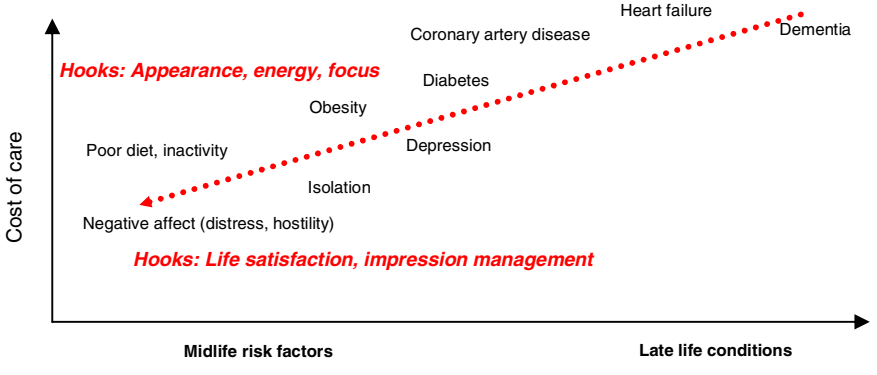

Fig. 1. Antecedents of heart failure and dementia that can be addressed in midlife. Most medical resources, and to date, health technologies, have focused on late stage conditions. This prospective approach focuses on early vulnerabilities and how those align with "hooks" – the concerns of individuals in midlife.

2 Reframing Risk: Leveraging Midlife Hooks

A key element of prospective health technology design is "meeting people where they are." These words of a master psychotherapist emphasize that clinicians need to understand the patient's perspective and his or her readiness to change. Technologists too must meet people where they are – their current concerns, values, health status, and life-stage. It is clear – from behavioral economics and our own ethnographic observations – that people generally do not forecast well. Decisions about health care and assistance in late life are often put off until a crisis, and made without the planning that would create optimal choices [13]. Technologies need to accommodate this myopic tendency by addressing present concerns – be they about appearance, relationships or mental focus – as motivating hooks that can be aligned with long term risks. For example, a 45 year old man who has slowly gained 20 lbs probably worries about attractiveness, but is less likely to calculate his body mass index relative to obesity criteria, much less his vulnerability to diabetes. Similarly, a woman prone to angry outbursts probably thinks more about the impression she makes on friends than her vulnerability to depression and ultimately cardiovascular disease. Immediate concerns about appearance and impression management, highlighted in the diagram above as "hooks," align easily with the long term costs of obesity and depression. Truly smart health technologies will support these present concerns while helping individuals avert associated long term risks.

3 Closing the Loop: Linking Assessment and Feedback

This preventive approach argued for here closes the loop between monitoring and intervention: Supportive, actionable feedback is generated from continuous assessment of behavior and physiology. In line with the approach of "embedded assessment," monitoring is woven into compensatory and preventive aids, and responsiveness to graduated cues provides nuanced data about the variability in an individual's functioning. This embedded assessment model emerged from observations that people often avoided clinical testing and diagnosis, but eagerly sought out with compensatory techniques and activities with preventive promise [14].

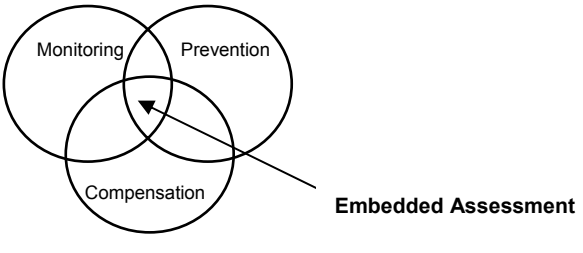

Fig. 2. Embedded assessment: Combining monitoring, prevention and compensation permits nuanced assessment and adaptive support. Model published and elaborated in [14].

An important goal in this feedback loop is to raise self-awareness and facilitate self-regulation. This goal, shared by mindfulness practitioners, is well aligned with technology miniaturization. We can now capture variability in health related data across a wide range of environments and help individuals understand and ultimately influence fluctuations in their physical and emotional states.

4 Dynamic Feedback: Presenting Context and Inspiration

To significantly influence health trajectories, we need people to make profound lifestyle changes and to maintain them over the long haul. As emphasized above, key changes include the ways people regulate their appetite, sleep, exercise, and responses to challenges. Feedback technologies will be most effective if physiology, emotion and behavior are viewed as a system [15]. In light of these goals, we need to rethink the way we reflect data and suggest change. Traditional biofeedback, which has been moderately effective in treating targeted problems such as Migraine headaches and Reynaud's disease, is a point of departure. But we need to move beyond granular depictions of muscle contractions. In particular, we need to convey context and inspiration for changing deeply ingrained behaviors.

Regarding context, new technologies are allowing us to bring therapeutic support into the environments of daily life and shape it to individuals' particular situations and needs. Specifically, wireless sensors, inference engines, and mobile interfaces can capture ecologically rich data and tailor feedback to an individual's current circumstance: where she is, her present company and activity. Some feedback is designed for on the spot assistance: Imagine a perfectly timed phone call that, based on physiological stress monitoring and sensing of kitchen environment, interrupts late night snacking. Other feedback is intended to foster self-awareness, invite goal setting and reinforce progress; such displays should reflect the convergence of contextual factors and their influence on health variables of interest (e.g., how smoking varies with social context, exercise and day of the week).

Regarding inspiration, feedback should suggest fluidity in mental and physical states. Studies on cognitive behavioral therapy and mindfulness practices have demonstrated the value of illuminating the changeability of negative situations [16,17]. Sensor technologies and inference engines are well suited to capturing variability. But we need to think carefully about how to display variability in a way that empowers change. In doing so, it is important to show individuals immediate evidence of their actions and allow them to conduct empirical experiments. Lagging indicators of behaviors that accrue over months, such as weight scale readouts, are often counterproductive. Pedometers by contrast, offer appeal of immediate feedback. Glucometers similarly allow immediate empirical evaluation -- a characteristic that has been leveraged in games designed for children [18,19]. Experimentation could be invited on a larger scale, relating for example, to social roles and styles and of reacting to stressors.

5 Example Displays

Following are display concepts intended to motivate behavioral change and prevent disease progression. These concepts vary in stage of development. The first ambient display has been fully integrated with a wireless platform and tested over months in the homes of elders and caregivers. The second and third are preliminary concepts for reflecting cardiovascular and weight changes to individuals with chronic conditions. The last is an exploratory sketch intended to convey the maladaptive dynamics of extended stress reactivity.

A Solar model of social engagement (Figure 3, see [20] for full description)**.** This display reflects data on co-present and phone interaction gathered from wireless sensor networks. We tested this display and platform of sensors and interventions with older adults at risk of isolation and associated problems, such as dementia. The elder, represented as the sun, is surrounded by planetary representations of friends and family who move inward with greater contact. The display was designed to raise awareness of social health as a dynamic and controllable aspect of well-being.

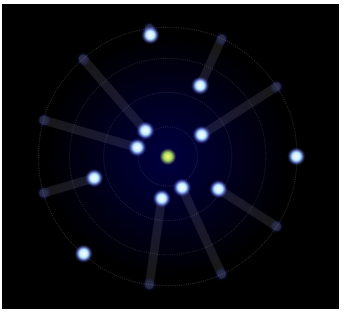

Fig. 3. A Solar model of social engagement

Removing shame from the scale (Figure 4)**.** This display of weight trends was inspired by studies of heart failure patients. Sudden weight gain reflects dangerous fluid retention that can be reversed through diuretic medications. But many avoid the

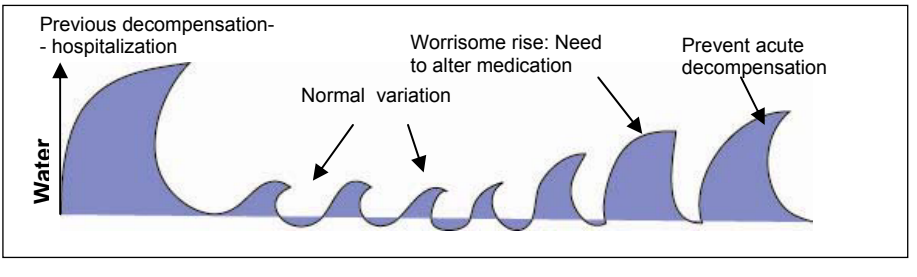

Fig. 4. Removing shame from the scale

scale. As one cardiac nurse explained, “No one, not even my male 80 year old, severely obese, late stage heart failure patients want to confront weight gain.” Water retention is here depicted as rising tides, distinguished from base weight. Patients can see the levels associated with a previous decompensation and normal variation. When levels rise above a threshold, the display also suggests need for corrective action.

Motivating safe exercise. This display, also inspired by studies of heart disease, concepts plots of activity levels against cardiovascular stress (Figure 5). Exercise holds long term benefit but is sometimes avoided due to short term risks associated with exertion. For this concept, activity and cardiovascular monitoring are embedded in a wireless earpiece. Feedback of current state and trends is presented on the screen of a mobile phone. In the example display, blooming flowers accompany the graphically depicted trend of increased activity and decreased cardiovascular stress. This prototype is being developed with Intel colleague Farzin Guilak.

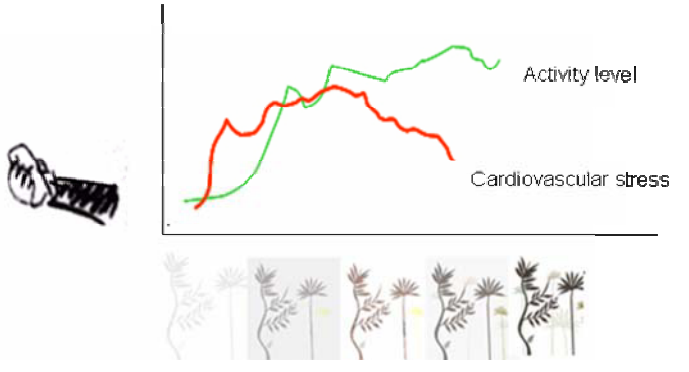

Fig. 5. Motivating safe exercise

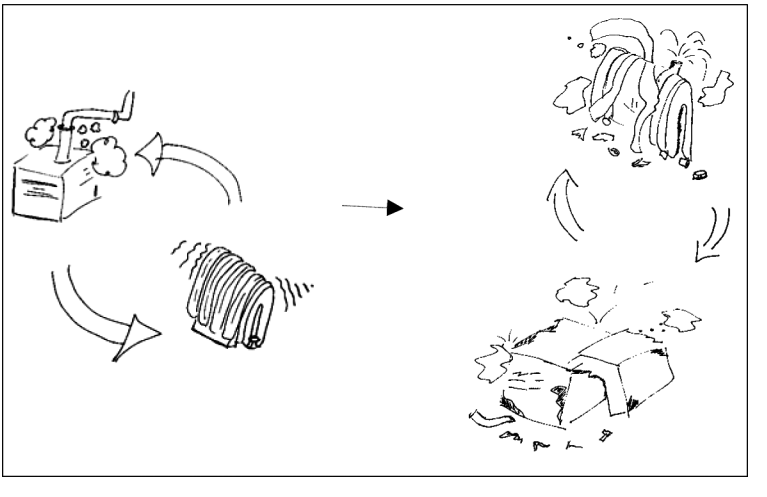

Fig. 6. Remodeling stress

Remodeling stress. This sketch (Figure 6), developed in collaboration with Bruce McEwen, is intended to convey the concept of "allostatic load" [5]. Extended autonomic imbalance is depicted metaphorically as an inefficient heating and cooling system . Blasting air conditioning over a heater on a warm spring day may produce an acceptable temperature in the short term, but will wear down the building over time. This deterioration represents the cumulative toll of stress reactivity on immune function and many aspects of health.

6 Future Directions

Prospective care will be greatly enhanced by collaborations between health and technology researchers on novel forms of feedback. The examples shared in this paper, and I believe most other feedback tools created to date, have focused on either physiology or behavior. The most important and challenging work will, as Schwartz suggested early on, explore the interplay of behavior, emotion and physiology [15]. We now have the tools to gather data in many contexts of life and make more informed inferences about these relationships. Some of the most challenging work will lie in determining the interventions or feedback approaches most effective in motivating change. Ongoing translation between what can be measured and what is meaningful for individuals will certainly be important. There will also be exciting opportunities to personalize and tailor messaging. Migrating therapy into everyday life holds great potential for interrupting the behaviors that are described but rarely demonstrated in clinical interactions. But to be effective, this "mobile therapy" needs to be as compelling as a cigarette, drink, donut, a hostile outburst, or ruthless self-criticism. Given the immediate pull of such stimuli and reactions, we must broaden the exploration of feedback from informational displays to experiential support.

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