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Vol. 8, No. 2
April–June 2009

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Most of us have experienced lying awake at night regretting something negative we said that was caused by our stress. We worry, with good reason, about the damage of words, said or unsaid, to relationships with friends, family, or colleagues or to our long-term health. If only we kept these post-event insights, like those garnered in therapy, in mind during the next stressful encounter. The devices we carry around now help us stay in touch with more people, more frequently, in more places, and with richer content; what if they also helped us communicate more effectively? Converging trends in personal technologies and personalized medicine raise the question of what life would be like if our phones—objects we've come to see as extensions of ourselves—could help us become more emotionally aware. How might we, our communication, and our relationships change?

Awareness of emotional patterns and the ability to modulate them are key for mental and physical health. These skills, described as mindfulness and self-regulation, can be facilitated through meditation and psychotherapy. Unfortunately, these time-consuming and sometimes costly practices are available to few and generally unavailable when stress strikes. Even those who have access to such therapies complain about leaving insights on the analyst's couch and intentional breathing on the yoga mat. The transition to applying these insights and skills in everyday life remains a challenge. Self-help books abound, but their message is that one size fits all, forever; they aren't tailored to individuals, much less their evolution over time.

The next compelling source of help might be the mobile phone. Our increasing reliance on our mobile phones and their inherent knowledge about us—our whereabouts, communication styles, and relationships—makes it seem increasingly likely that for many people the mobile phone will emerge as the preferred personal coach of the 21st century.

What would life be like if our phones could help us become more emotionally aware? How might we change?

MOBILE THERAPIES

Mobile therapy—just-in-time coaching that is triggered by physiological indicators of stress—is the objective of Mobile Heart Health, an exploratory research project at Intel. The project aims to help people tune in to early signs of stress and modulate reactivity that could potentially damage their relationships and long-term health. This approach is aligned not just with mindfulness practices but also with the broader agenda of preventive medicine. Cardiovascular health is particularly vulnerable to prolonged stress reactions and is increasingly understood as an accumulation of behaviors, perceptions, and emotional reactions throughout life. Cardiovascular disease progression is influenced by an array of stressors, including hostility or proneness to interpersonal conflict.[1] Accumulated interpersonal stress, along with insufficient sleep, poor nutrition, and inactivity, leads to prolonged deregulation of the autonomic nervous system and what is termed "allostatic load."[2]

Our research explored a closed loop of biosensing and mobile feedback based on the model of embedded assessment, which integrates monitoring, compensatory feedback, and prevention.[3] The feedback takes the form of mobile therapies that appear on the cell phone in response to cardiovascular signals (see Figure 1) or when the system detects contextual shifts associated with stress. Moment-to-moment changes in heart rate variability, indicative of stress, trigger feedback (mobile therapies) for emotional regulation. According to this model, the monitoring recalibrates by sensing (via electrocardiograph, ECG) and tracking usage of mobile therapies—for example, whether someone responds to subtle cues or requires blatant instructions to

SPOTLIGHT

Figure 1. Mobile Heart Health. A wireless ECG detects changes in stress levels as measured by deviations in heart rate variablity and triggers mobile therapies.

Figure 2. Mobile therapies. These breathing and cognitive reappraisal techniques provide just-in-time coaching.

regulate physiological functioning. The measurement of how effective a particular exercise is in a given context adds to the assessment gathered by the wireless ECG sensing. Far from the yearly check-up, embedded assessment illuminates 24-hour patterns, contextual factors, and therapeutic responses.[3]

We assessed contextual changes associated with stress through location sensing, synchronization with calendaring applications, and experience-sampling methods. Subjective assessment occurred through touch screen adaptations of clinical scales. Variability in these triggers helped the system determine the stage of stress and the appropriate flow of mobile therapies. We also developed software to permit highly configurable and personalized mobile therapy protocols.

The chief mobile therapies in this study included breathing and physical-relaxation exercises (the Body Scan), cognitive-reappraisal prompts (the Mind Scan), and coaching for collaborative communication (see Figure 2). The techniques were inspired by cognitive behavioral therapy,[4] yoga, and mindfulness practices but adapted for the mobile phone. Extended dialogues, appropriate for a clinical or class situation, were translated for mobile interfaces and the limited time periods that people engage with them. These adaptations, which range from interactive visualizations to mood-based media, were informed not just from clinical protocols but also by ethnographic observations about how people experience stress in daily life. Personal strategies such as imagery, music, and mantras offered hints for abbreviating and modernizing clinical techniques.[5]

MEASURING STRESS IN EVERYDAY LIFE

Researchers and clinicians have a long history of employing physiological indicators to quantify and characterize stress response—the body's reaction to a real or implied threat. Stress response affects the subject's autonomic nervous system, causing sympathetic activation and parasympathetic withdrawal. This change, coupled with existing disease conditions, impacts blood pressure, respiration rate, pupil dilation, heart rate, and numerous other physiological factors. Rosalind Picard's work in affective computing provides some understanding of diurnal stress patterns.[6] Although any of these measurements could be used to drive in-the-moment therapeutic response, we chose to implement a small, wireless ECG sensor, primarily because of its unobtrusive nature. Unlike blood pressure cuffs (which are bulky and require periodic inflation), pupil-tracking systems (necessitating head-mounted cameras), or galvanic skin response measurement (requiring electrodes on the hands or feet), the ECG operates continuously and unobtrusively and provides a wealth of information on subjects' autonomic tone and cardiovascular health. In addition to heart rate measurements, we can use a quality ECG signal to calculate heart rate variability (HRV): minute changes in beat-to-beat intervals that are correlated with stress response and disease state. Activation of the sympathetic nervous system and withdrawal of the parasympathetic system both reduce the higher-frequency components of HRV, while deactivation of the sympathetic and activation of the parasympathetic increase higher-frequency components. In other words, increased stress reduces the fluctuation in beat-to-beat intervals, whereas decreased stress increases fluctuation.

These measures are highly sensitive to stress and can vary greatly between individuals depending on age, health status, medications, activity, and other factors, so stress response detection must be measured as a relative change to a baseline value. To address these individual differences, each subject's baseline and stress threshold are established in a lab setting using a protocol intended to alternately evoke sympathetic and parasympathetic responses. In addition, the system must account for variability in stress measurements owing to activity, location, and social situation. The ECG sensor that we prototyped incorporates a triaxial accelerometer to detect activity and body orientation, and the cell phone application queries the subject on location, companions, and other contextual information. By recording the subject's response to therapeutic interventions driven by the sensor, the system can continually calibrate its threshold values, adapting to changes in the subject's emotional state.

FIELD TESTING

We conducted preliminary testing to evaluate the system's ability to detect distress and deliver a just-in-time mobile therapy. Colleagues volunteered to use the system, comprising the ECG sensor and cell phone, under a mock stress situation: they received accusations of poor work performance in front of others. We planned these hostile exchanges so that the accusations would catch the volunteers off guard. The phone monitored heart rate variability using the RMSSD (root-mean-square of successive differences) algorithm[7] and displayed a breathing visualization when the sensor detected a significant drop in HRV. The breathing visualization, an expanding and contracting blue circle (shown in Figure 2), remained on the screen until heart rate variability returned to its normal range. In this particular field test, which involved both ECG testing and mobile therapies, we restricted the mobile therapy to the breathing exercise. In other field studies that didn't use the ECG sensor, we tested a far broader array of the mobile therapies, some of which we described earlier. In those broader studies, mobile therapies were triggered by self-reported mood, as gathered by the experience-sampling application on the cell phone.

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Participants in system tests found the ECG monitor to be reasonably wearable (some described it as "nurse chic") and the phone displays (breathing visualization and mood scales) to be intuitive and easily adjustable. Some complained of skin sensitivity owing to the large surface area of adhesive on the electrode. Even though we reduced sensor size significantly throughout design iterations, we believe that wearability concerns will persist until wireless, noncontact sensors are perfected. Even then, a segment of the population will likely refuse to continually wear a sensor and will require that any sensing be integrated into the environment or the communication device itself. Like pedometers, which have gone from the hip into cell phones, manufacturers are exploring ECG sensing within phone hardware.

In terms of functionality, the system successfully displayed the breathing exercise in response to detected stress. However, stress indicators varied across individuals even more than we anticipated from previous research. Colleagues of similar age, physical fitness, profession, and personality style differed dramatically in their HRV baseline and threshold values. This variability underscores the importance of an adaptive system that continuously self-calibrates by combining physiological measurements with feedback from the user. Individuals also differed considerably in their preferred breathing rates. The breath visualization operated at several paces but would ideally match the individuals' respiration rates and help them slow down gradually. The preferences we observed in breathing depended on ethnicity and habits: participants from India and those who practiced yoga, for example, preferred much slower progression of the visualization than those who were from the US and those who had no experience with deliberate breathing.

The testing underscored the sensitive but nonspecific nature of HRV sensing. The sensor readily detected many sorts of emotional changes. To discriminate more accurately among different emotions, a hybrid stress detection approach involving multiple unobtrusive sensors could be useful. For example, adding measurements of speech or respiration rate might reduce false positives indicated by ECG and enable more accurate characterization of emotional changes. Given the

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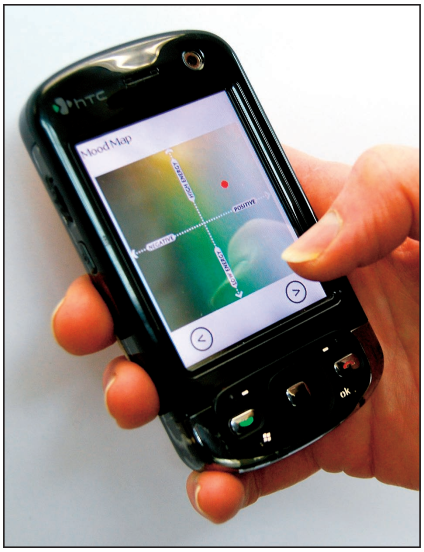

Figure 3. The Mood Map. This touch-screen translation of the circumplex model of emotion[9] allows quick intuitive reporting of emotional states throughout the day.

Figure 4. Stage-based coaching. Selecting an image produces mobile therapies to help the user avoid, manage, or process a stressful encounter.

nonspecificity of sensing, however, we believe that it is and will be important to invite user annotation of emotional experience. We developed a variety of touch-screen mood scales for this project. An experience sampling software application, MyExperience[8] allowed individuals to report their emotional states throughout the day. The main mood scale was the "Mood Map,"[5] which, based on the circumplex model of emotion,[9] invites users to quickly indicate mood states according to valence and arousal (see Figure 3). These subjective reporting techniques were desirable as checks on sensors, and in their own right as brief windows for self-awareness.

This evaluation and broader deployments we've conducted on a portfolio of mobile therapies revealed strong interest in real-time interventions for stress management. Equally compelling for many participants was the prospect of seeing trends of their moods over time, particularly as they correlate with behaviors such as eating and sleeping. Ideal candidates for this technology appear to be people who are "aware that they are unaware," those who recognize that stress affects their relationships and health and want to more effectively modulate their emotional, physical, and behavioral reactions. Many expressed interest in the application as a way to curb related problems such as stress eating; as one woman wished, "If [only] this thing could know that I was stressed and tell me to do something other than eat." The breathing visualization was popular as a quick way to address irritation at work and home. It was used to guide breathing, as a meditative visual, and as a simple indication that one's physical state had changed. The most surprising use was as an aid for children's temper tantrums. Preferences for other mobile therapies, tested in field trials using mood scales rather than the ECG sensor to trigger help, varied considerably. Some liked blatant interventions such as the "exit strategy," in which the phone fakes a call away from a stressful encounter, while others preferred tools that helped them prepare for stressors or practice general techniques.

The therapies and visual metaphors were intended to help people shift from a reactive to a proactive coping style. The menu for selecting coaching, shown in Figure 4, conveyed the arc of interpersonal conflict—from a match to a forest fire—to encourage people to "catch the flicker before the flame." The therapies triggered by each icon included coaching for constructive communication and problem solving appropriate for that stage of stress. Testing over longer stretches of time could reveal whether individuals shifted from emergency interventions to anticipatory aids.

MEANINGFUL COACHING

This project extended previous research on ambulatory monitoring by translating cardiac data into on-the-spot coaching. The intent was to provide more actionable coaching than the displays of physiological data traditionally used in biofeedback. Previous ethnographic research indicated several limitations of that traditional biofeedback. First, granular plots of cardiac data can be overwhelming to people seeking intuitive and holistic guidance for life improvement. Like weather maps, which have evolved from detailed numeric tables into dynamic storm maps, biofeedback must extend from ECGs to intuitive metaphors of stress management. Second, for many people, relationships and appearance are more powerful than long-term risk reduction as motivational hooks for behavioral change. The threat of heart disease might be experienced as a remote and abstract threat compared to palpable near-term risks such as losing a job or marriage.

Hence, coaching that is framed in terms of interpersonal effectiveness or physical appearance might be more powerful than biofeedback graphs or long-term estimates of health risk. Many of the mobile therapies we tested in our broader field deployments focused on goal prioritization and empathic communication. An example is shown in Figure 5.

Future research will explore a range of biosensors to illuminate emotional states and a broader range of interfaces for providing on-the-spot therapies. Voice is an obvious next metric to explore for measuring stress and delivering therapies. Many participants also expressed a desire for a far wider range of breathing, yoga, and physical relaxation exercises than those included in this research.

Future development should also explore community applications for mobile therapies and assessments. Even though they were intended as personal tools, many participants in our field studies used the mobile therapies to coach or confront other people. Others expressed a desire to see the mood trends beyond their own—either of dynamics within a couple or of a larger group. Perhaps the next world crisis will be described with a collective ECG, mood ratings, and visualizations that are more helpful than graphs of plummeting stock prices. ◼

Figure 5. Mobile therapies translate biofeedback into cues for empathic problem solving.

ACKNOWLEDGMENTS

This research was done in collaboration with Intel team members including Bill Deleeuw, Michael Labhard, J.M. Vanthong, Gail Block, and Sengul Vergun. Special appreciation is owed to the interaction designers on this project: Qusai Kathawala, Dominic D'andrea, and Stefanie Danhope-smith. We also thank colleagues Richard Sloan and Ethan Gorenstein from Columbia University and Larry Jamner from the University of California, Irvine.

The application featured in this article was developed for research purposes only.

REFERENCES

1. R.P. Sloan et al., "Hostility, Gender, and Cardiac Autonomic Control," *Psychosomatic Medicine*, vol. 63, 2001, pp. 434–440.
2. B. McEwen, *The End of Stress as We Know It*, Nat'l Academies Press, 2002.
3. M. Morris, S.S. Intille, and J.S. Beaudin, "Embedded Assessment: Overcoming Barriers to Early Detection with Pervasive Computing," *Pervasive Computing*, LNCS 3468, Springer, 2005, pp. 333–346.
4. E.E. Gorenstein et al., "Cognitive-Behavior Therapy for Reduction of Persistent Anger," *Cognitive and Behavioral Practice*, vol. 14, 2007, pp. 168–184.
5. M. Morris, "Technologies for Heart and Mind: New Directions in Embedded Assessment," *Intel Technology J.*, vol. 11, no. 1, 15 Feb. 2007.
6. R.W. Picard, *Affective Computing*, MIT Press, 2000.
7. Task Force of the European Soc. of Cardiology and the North Am. Soc. of Pacing and Electrophysiology, "Heart Rate Variability: Standards of Measurement, Physiological Interpretation, and Clinical Use," *Circulation*, vol. 93, 1996, pp. 1043–1065.
8. J. Froehlich et al., "MyExperience: A System for In Situ Tracing and Capturing of User Feedback on Mobile Phones," *Proc. 5th Int'l Conf. Mobile Systems, Applications, and Services* (MobiSys 07), Usenix, 2007, pp. 57–70.
9. J.A. Russell, "A Circumplex Model of Affect," *J. Personality and Social Psychology*, vol. 39, 1980, pp. 1161–1178.

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