A Personal, Mobile System for Understanding Stress and Interruptions

by
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Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of

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Abstract

There is a variety of emerging health applications that monitor a person's physiological signals over time -- from a growing interest to monitoring elders in cognitive decline, to systems that monitor and understand stress. While some may remain implicit monitoring devices, there is a subset of them that require interactions with a user. This thesis focuses on the challenges inherent to an interactive, health system – how and when to interact with a user. This research aims to improve these systems by using: 1) affect-sensitive strategies though social-emotional dialogue, and 2) interruption-sensitive strategies through adjusting the timing of these interruptions. An interactive, health application has been developed for data collection, annotation, and feedback that is part of a longer-term research plan for gathering data to understand more about stress, the physiological signals involved in its expression, and how that might interplay with interruptibility. The system has been developed on a mobile platform and uses affect and interruption-sensitive strategies to engage users and allow for real-time annotation of stress, activity and timing information through text and audio input. The platform supports continuous, wireless, and non-intrusive collection of heart signal data, accelerometer, and pedometer information, as well as automatic labeling of location information from context beacons. This system is the first of its kind to be affect and interruption-responsive – to use physiological data to adjust the timing of interruptions, as well as to adaptively respond with dialogue and relational strategies that specifically address the user's stress levels and the disruption the device may be incurring upon the user.

The system has been evaluated with seven subjects who used either the responsive or non-responsive system for four days, then used the opposite system for another four days, and finally, were asked to choose which system to continue interacting with for the last four days. The affect and interruption responsive system was rated as significantly less stressful on users, and five out of seven of the subjects chose to continue working with the responsive system. This study has demonstrated that designing platforms that are relational and responsive to a person's affect can facilitate a less frustrating and more enjoyable experience over time, even in tasks that are highly disruptive.

Overall, this thesis has contributed not only a new system for gathering annotations useful for studies of stress, but also provided new insights into the value of using relational and attentional strategies in a task that involves a large number of interruptions.

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Above all, I thank God – the source of my passion for creating technology to transform and augment the world. 1 Corinthians 15:58

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

There is a variety of emerging health applications that monitor a person's physiological signals over time (Tran 2000; Miller 2001; Cole 2002) -- from a growing interest to monitoring elders in cognitive decline (Morris, Lundell et al. 2003), to systems that monitor and understand stress. Many of these systems may remain implicit monitoring systems, such as a diabetic (Kinsella 1999) or cardiac monitoring system that relays information to a central server or alerts friends or family in warning situations. However, a subset of these types of applications will assess affect and medical states and require interaction with the user. This thesis focuses on the challenges inherent to an interactive, health system – how and when to interact with a user. This research aims to improve these systems and provide insight on how to develop technologies that can better engage users in two main ways: 1) explore *how* to interact through social-emotional, relational, responses, and 2) explore *when* to interact by adjusting the timing of these interruptions.

The following section describes a motivating application which uses these strategies in an interactive health system to understand stress and how that stress might interplay on interruptibility. The results shown in this thesis are not unique to understanding stress, but apply to all systems that require interacting with users.

1.1 Motivating Application

Stress is useful. The extra burst of adrenaline helps you run away from an attacker, finish that final paper, and win at a sports meet. When we are stressed, the sympathetic nervous system, which causes accelerated heart beat, dilated pupils, secretion of adrenaline, and inhibited digestion, is activated (Sapolsky 1998). Yet prolonged stress is damaging. If we are always stressed, the parasympathetic side of the brain -- the side that slows heart beat, constricts pupils, and stimulates digestion – is suppressed. The diseases that predominantly affect us now are ones of slow accumulation -- heart disease, cancer, cerebrovascular disorders – diseases which are complexly intertwined with our emotions, physiology, immune system, personalities, and behaviors. Stress does not necessarily make us sick, but it does influence our immune system and the hormones that affect our susceptibility and recovery from illnesses (McEwen and Stellar 1993; Sapolsky 1998; 2003). Negative affective states, such as anger and hostility, have been linked to heart disease (Barefoot, Dahlstrom et al. 1983; Barefoot, Dodge et al. 1989). It is clear that emotions and stress impact health; however, the influence of either has been hard to measure in any precise ongoing way and currently, there are no quantitative tools for analyzing how stress levels interact with our activities and behaviors. Without the ability to measure stress and a basic understanding of how stress correlates with our physiology, it is difficult to manage the disease. This application builds a system for data collection, annotation, and feedback that is part of the longer-term research plan to gather data to understand more about stress and the physiological signals involved in its expression, as well as to understand how stress might interplay with interruptibility in a highly disruptive task such as annotating activity and stress information. Feedback and visualization tools are developed to allow users to reflect and understand how their activities interplay on their heart in order to increase self-efficacy in motivating a healthy lifestyle.

One particular difficulty in understanding stress is that it requires gathering huge amounts of labeled data, an arduous and tedious process. One argument against this concern is that only the initial training period for developing statistical models may require large amounts of annotated data -- future users will not experience the same tedious process. Regardless, in this type of interactive, annotation system, the success of such applications is dependant on acceptance from users, therefore, it is paramount that this type of system be affect and interruption-sensitive; not only should it adjust the timing of interruptions, but it should adaptively respond with dialogue and relational strategies that specifically address the disruption the device is incurring upon the user. This thesis presents one possible interactive, health application developed on a mobile platform that allows for continuous, real-time user annotation of stress, activity and timing information through text and audio input, and evaluates the benefits of using affect and interruption-sensitive strategies to improve on when and how to engage users.

1.2 Summary

In this chapter I have motivated the development of an affect and interruption sensitive, real-time, collection and annotation device for understanding stress and interruptions. The reminder of the thesis is organized in the following manner:

- Chapter 2 discusses previous work in health monitoring systems, experience sampling methods, and relational agents that creates a foundation for this work.
- Chapter 3 discusses the implementation and design of the continuous annotation platform.
- Chapter 4 presents the evaluation of the system from Chapter 3 involving seven subjects who interact with the system daily for eight to ten days.
- Chapter 5 summarizes my results and discuses future work in mobile, health systems that require a long-term interaction with users.

Chapter 2

Previous Work

Most of the work regarding using physiological signals for learning about affective states has focused solely on the recognition problem (Vyzas 1999; Healey 2000; Picard, Vyzas et al. 2001) without integrating it with a system that responds and adapts to affect. Picard defines "affective computing" as computing that relates to, arises from, or deliberately influences emotions (Picard 1997) and has looked at wearable devices with a Motorola cell phone for monitoring stress (Picard and Du 2002). Figure 2-1 gives an example of a driver's "stress" in Boston using one proposed method of measuring stress developed by Yuan Qi at the MIT Media Lab and used in this thesis. The figure is derived from a driver's electrocardiogram (ECG) over seventy-five minutes behind the wheel of a car from a driver stress study by Jennifer Healy at MIT (Healey 2000). The signal tends to be highest during stressful city driving and lowest on the straight highway stretches and during the first and last fifteen minutes, where the driver was instructed to sit quietly in the parked car, with her eyes closed. Typically, the last fifteen minutes shows a steady decline in the stress signal of the driver. However, in the episode here, the driver's signal suddenly climbs again, coincidently with the arrival of a loud siren in the distance. One plausible explanation is that the subject's mind was engaged in stressful thoughts related to the siren; subsequently, this stress showed up in the subject's heart, although to an outside observer, the subject appeared to be relaxed.

There has been increasing interest in using computer sensors in learning and reasoning about interruptibility and attention (Horvitz and Apacible 2003; Horvitz, Kadie et al. 2003; Hudson, Fogarty et al. 2003) and a wealth of literature on understanding interruptions. While there has been a limited amount of work using biological sensors to explore interruptibility, there has been almost no work to date that combines physiological sensors with an interactive, social-emotional responsive system.

2.1 Health Monitoring Systems

The current standard procedure for monitoring patients with long-term cardiovascular disorders is the Holter Recorder, originally developed in 1949 by Norman J. Holter (Holter 1949). Signals are recorded on cassette and then analyzed off-line using dedicated diagnostic systems after the data is uploaded to a dial-up server. New generations of Holter devices have been developed using solid-state memory instead of magnetic tape as the recording medium (Jovanov, Gelabert et al. 1999), but with the same analysis overhead and functional limitation to passive observation without the ability to intervene or annotate significant events in real-time (pen and paper is used).

Current commercial devices that enable physiological monitoring with real-time feedback include Polar, Fitsense Technology, the LifeShirt system, and Body Media (VivoMetrics 1999-2004; BodyMedia 2004; Fitsense 2004; Polar 2004). These systems can collect, store, and display information for real-time or offline use, but do not use active monitoring methods that adapt to the user. Tim Hirzel (Hirzel 2002) developed tools to visualize the hidden exercise in daily heart rate data, but also used a passive data collection device with pen and paper annotations.

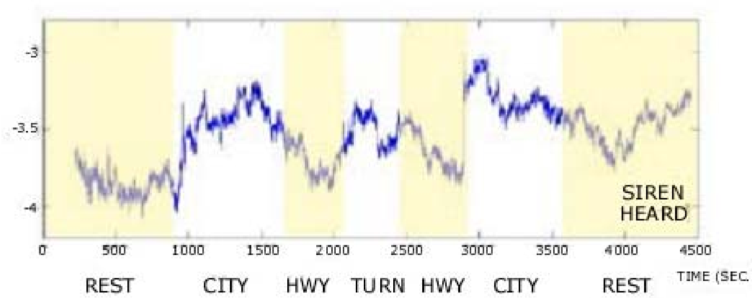


Figure 2-1 “Stress” for a driver in Boston

The Institute of Heartmath has developed an interactive health-monitoring system (McCraty, Atkinson et al. 1999) that allows a user to visualize his or her heart rhythms as a display (such as a hot air balloon) that adapts to their heart. McCraty et al. (McCraty, Atkinson et al. 1995; McCraty 1998) have shown how emotions such as anger and appreciation have significant effects on heart rate variability, in particular, affecting the sympathovagal balance. While both anger and appreciation increased overall autonomic activation and produced an increase in sympathetic activity, feelings of appreciation produced a shift in the amount of energy toward mid- to higher-frequency components of the heart rate variability power spectrum. It is hypothesized that such measurable influences of affect on the heart may be, in part, responsible for some of the influences that states such as hostility have on heart disease.

Vadim Gerasimov at the MIT Media Laboratory introduced *Every Sign of Life* (Gerasimov 2003), an approach and motivational schema for personal health monitoring that explores how to make the information collected by these devices fun and engaging. Gerasimov showed how this approach could be used in stress monitoring – by overlaying biosensor information onto a calendar or detailed schedule of events, a user would be able to see how their stress correlated to their daily activities. This research proposes to develop a more enjoyable way of collecting the event annotations necessary for understanding stress, rather than focusing on how to make the information collected after the fact more engaging.

2.2 Experience Sampling Method

The method of obtaining stress, timing, and activity labels closely follows the Experience Sampling Method (ESM), also known as Ecological Momentary Assessment (EMA) (Csikszentmihalyhi and Larson 1987) -- an *in situ* sampling method often used in the field of psychology and recently more widely used to evaluate and assist in the development of ubiquitous computing applications (Walker and Consolvo 2002). EMA techniques use paper or electronic diaries to record single acts or extensive concurrent self-reports (within-days, over several days) about behaviors, experiences, and their context in order to minimize recall issues and observe phenomena as they occur in natural settings (Schwarz and Oyserman 2001).

Traditional ecological momentary assessment tools with random or fixed timing prompts are disruptive in the long-term and often miss key events. The disruptiveness of these devices hinders long-term acceptance of ubiquitous health systems and without a system that respects your efforts to provide data, thinks a little bit before interrupting you, and tries to make the task as simple and enjoyable as possible, users will eventually refuse to interact with these devices. The most advanced work done in this area is through the *Context-aware experience sampling* (CAES) system (Intille, Rondoni et al. 2003) which improves upon ESM/EMA by using sensing technologies to automatically detect events that can trigger sampling. While this system takes a first step towards capturing key events that may occur, it still does not take measures to address the additional disruption that may incur on the user. The system developed in this thesis draws from the design of CAES but provides additional support to providing a more enjoyable experience for the user through relational responses to a user's stress levels.

A particularly interesting work has been a diary study using ESM techniques to study task switching and interruptions with information workers (Czerwinski, Horvitz et al. 2004).

2.3 Relational Agents

The work done with relational agents (Bickmore 2003; Bickmore and Picard 2004), defined as computational artifacts designed to build long-term, social-emotional relationships with their users, and systems for managing user affective state, such as the one developed by Klein (Klein 1999; Klein, Moon et al. 2002) which was demonstrated to provide relief to users experiencing frustration, are the most relevant to this work. Examples of some relational agents, mostly toys, developed over the years include Sony's AIBO robotic dog, the Tamagotchi, Hasbro's Furby, and iRobot's My Real Baby. Bickmore's Laura (Bickmore 2003) in the FitTrack system was the first such relational agent designed to maintain a long-term relationship with a user and evaluated to investigate the role of these relationships in effecting instrumental task outcomes.

In their book *The Media Equation*, Reeves and Nass (Reeves and Nass 1996) demonstrated that people interact with all types of media, including their computers, in a natural and social way. Many of the strategies that are used to develop relationships between two entities are most effectively done through natural language dialogue. Theories such as politeness theory (Brown and Levinson 1987) implemented in computer systems that incorporate social deixis (language used to set relational expectations) (Walker, Cahn et al. 1997) provide guidelines for using natural language for relational communication.

Chapter 3

Implementation and Design

The development of interactive, annotation technologies for long-term health understanding presents many significant design and engineering challenges. Since the success of such devices is dependant on acceptance from users, it is paramount that this type of system be interruption-sensitive; not only should it adjust the timing of interruptions, but it should adaptively respond with dialogue and relational strategies that specifically address the disruption the device is incurring upon the user.

The system presented in this chapter allows for interactive, real-time user annotation of stress, activity and timing information through text and audio input on a mobile platform. It also allows for continuous, wireless, and non-intrusive collection of heart signal data (which is used to detect stress), accelerometer, and pedometer information, as well as automatic labeling of location information from context beacons.

Two versions of this system were created in order to support the experiment in the following chapter: a stress-responsive and interruption sensitive system, and a non-responsive and non-interruption sensitive system.

3.1 Requirements and Specifications

The personal, mobile data collection and annotation platform, known as PMobile, was designed for portability, ease of use, and continuous usage. The physiological sensors needed to be non-intrusive, thus wireless sensors developed by Fitsense Technology that communicated with a connector on an iPAQ were chosen above other more robust, wired solutions. The Fitsense Heart

Strap was used rather then the comparable Polar Heart Monitor (Polar 2004) since the Polar wireless transmission protocol was found to be disrupted by the low frequency of a car engine (heart information while subjects were in a car was particularly interesting for this thesis).

Easy-to-use buttons with dynamic text were used rather than speech recognition or natural handwriting on the iPAQ since speech recognition for a mobile device platform introduces constrained memory problems as well as high error recognition rates. Very limited natural handwriting was used since the annotation process needed to be extremely quick and easy and keyboard input is more tedious for a user.

3.2 System Architecture

Figure 3-1 shows the overall architecture for the PMobile system.

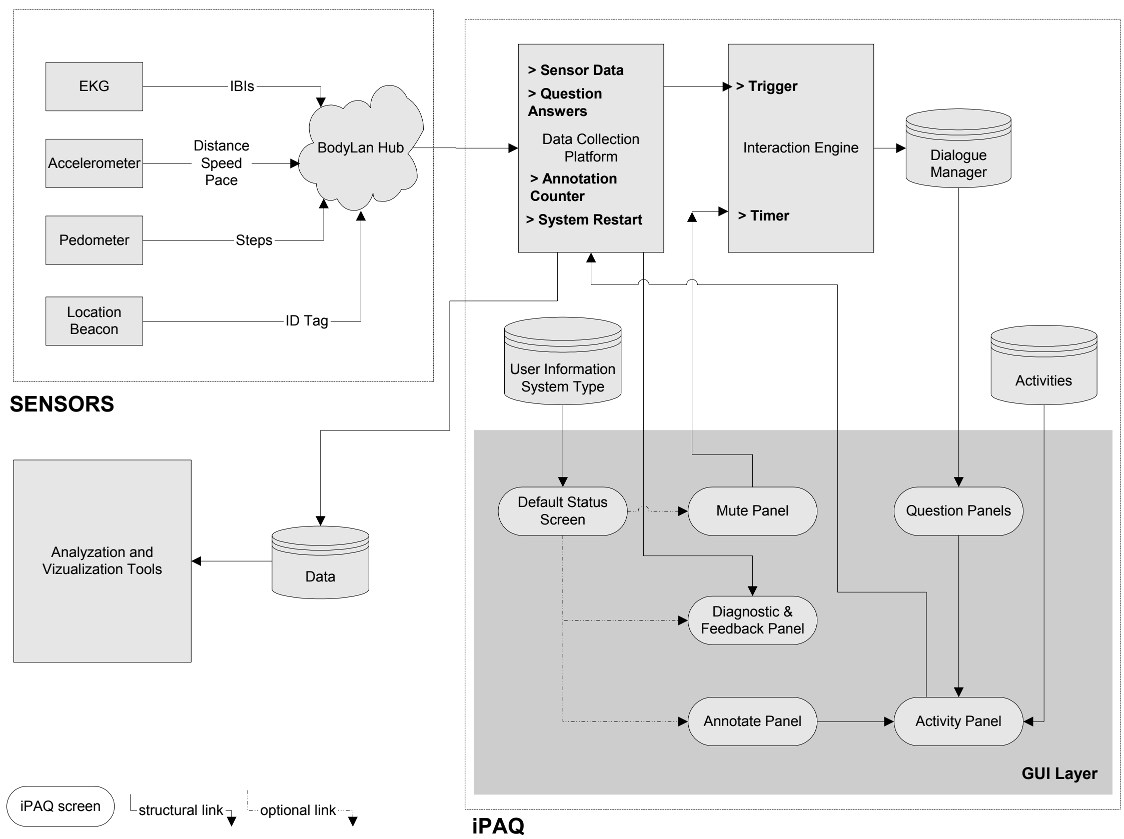


Figure 3-1 System Architecture

The continuous annotation system was developed in Embedded Visual C++ 4.0 and runs on a HP 5550 iPAQ running Windows CE 4.0. The system consists of a sensor layer that communicates to a *Data Collection Platform*. The *Interaction Engine*, based off of the CAES Engine (Intille, Rondoni et al. 2003) described in Chapter 2, schedules interactions to interrupt the user for annotations either through a timer or through triggers from the sensor information. The Interaction Engine uses a *Dialogue Manger* to choose from a set of different interaction scripts and possible responses to user input. A GUI layer receives input from scheduled and triggered interactions, as well as the possible question/response scripts, and interacts with the user through different GUI screens. The following sections describe each of these pieces in greater detail.

3.2.1 Sensor Hardware

The sensor hardware, shown in Figure 3-2, consists of set of custom-developed physiological sensors from Fitsense Technology (Fitsense 2004) – a Pulser for electrocardiogram (ECG) information, a Footpod for accelerometer information, a Pacer for pedometer information, and Location Beacons for environment context information.

Since factors such as exertion, as well as emotional stress or arousal, contribute to increases in heart rate (General 1996), an accelerometer was combined with heart rate recordings to give a better assessment of cognitive stress as some studies have done to isolate exertion (Strath, Bassett et al. 2002). A BodyLAN Hub (BLH) connects the iPAQ to the different sensors on a BodyLAN wireless network.

The BLH communicates with the iPAQ through a 4800 baud serial connection with two data lines: transmit and receive. The serial connection uses eight data bits, one stop bit, no parity bit, and no flow control. The BLH stores the latest message from each of the sensors and holds a settable reply message for each. Each BodyLAN Hub is assigned its own 32 bit address to ensure that there is no interference between two sensors on different network IDs (such as two Pulsers on different systems). The BLH has two high level modes: normal and learn. When the BLH and the sensor are both in learn mode, the BLH will automatically acquire the sensor, add it to its registry, assign the sensor an index, and switch the sensor from learn to normal mode. In normal mode, the BLH will only accept data from sensors with its own network ID and public sensors (such as the location beacons).

Figure 3-2 Sensor System

The Pulser is set to transmit information every two seconds using a Data Variant 3 that was developed for this research. Data Variant 3 transmits a data message containing the beat count and the last sixteen inter-beat intervals (IBIs) in milliseconds. The major features of the electrocardiogram are the P, QRS, and T waves which are caused by the corresponding electrical impulses in the heart of atrial depolarization, ventricular depolarization and ventricular repolarization (Mohrman and Heller 1991; Dubin 1996). IBIs are derived from the R-waves of the ECG shown in Figure 3-3 by taking the time interval from the top of the QRS complex to the top of the next QRS complex.

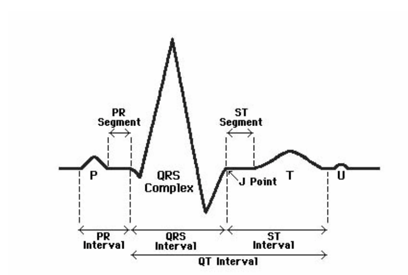


Figure 3-3 Normal Electrocardiogram

The accelerometer sends pace (m/min), distance (miles), speed (mph), and calorie (cals) information. The pedometer sends number of steps and the context location beacon sends a settable ID tag (i.e. ‘kitchen’ as a string or ‘24’ as an ID number).

Each sensor uses a three volt, 20mm lithium coin battery. The heart strap, accelerometer, and pedometer battery lasts about 60+ hours, while the location beacon battery lasts about two months.

3.2.2 Data Collection Platform

The Data Collection Platform interfaces with the sensor layer and question GUI panels to maintain the sensor data and question answer repositories. The sensor data repository stores all data from the sensors with a system timestamp and date to be used for offline learning and visualization. The question answer repository stores the user’s answers to each question in the scheduled or triggered interactions, the date of each interaction, the start and stop time of each question, the amount of time between the system beep prompt and the user answering the device, as well as all annotations that the user may have initiated from the default status screen. All data is stored in the iPAQ File Store on the device to ensure that the data will not be lost even with a hard reset to the iPAQ or if the battery is drained.

The data collection platform also uses the incoming data to maintain two different values: a daily annotation count and a system reset check. The daily annotation count is displayed at the end of every user-initiated interaction. If the system detects that the user has restarted the program due to a system error or sensor malfunction that day, instead of entering into a new annotation series, the program responds with “Its looks like you just restarted. Sorry about that. :(” The reset check was used in both conditions as a response to any user frustration from having to restart the system.

3.2.3 Interaction Engine

The main function of the Interaction Engine is to schedule the timing of each of the daily annotation sessions. There are two main ways that the PMobile system schedules interactions: through a timer and through a trigger from the sensor data. Timed interactions are set to a randomly selected interval between a specified minimum and maximum number of minutes from the last session to ensure that questions are asked throughout the entire day, but that there is some degree of randomness in the interruptions.

Although the sensor data repository stored data for offline use, the triggered interactions use the sensor data from the Data Collection Platform in real-time to immediately start an interaction session. Sessions can be triggered through a location change and through an event from the user's heart. Using the changing ID's from the location beacons, the system can determine where there is location change and trigger an annotation session when the user arrives at the new location. To detect a heart event, the Interaction Engine first takes each incoming IBI in milliseconds and divides it by 60000 to convert the value to instantaneous heart rate in beats per minute (bpm). Figure 3-4 shows the heuristic used to detect an interesting heart event. If there are five consecutive beats that are greater than 50% of the resting heart rate, the event state enters an elevated heart state. From that state, if the system detects five consecutive beats lower or equal to the resting heart rate, the event state returns to the normal state and triggers an interaction. Five consecutive beats were used to ensure that the system did not trigger from any noisy data. While there is an uncertainty whether this heuristic is a good trigger for signaling good or bad interruption times, this rule was selected since a consistent return to a normal heart rate from an elevated heart rate implies that the user was potentially experiencing a period of either physical exertion or psychological stress. Using the accelerometer data in conjunction with the heart rate detection algorithm, we can begin to separate out heart events from physical exertion.

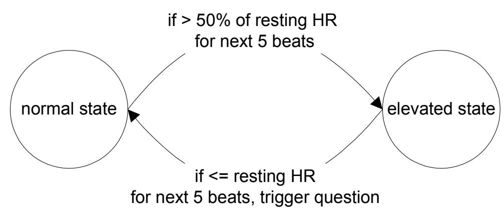


Figure 3-4 Heart Event Trigger Algorithm

3.2.4 Dialogue Manager

The Dialogue Manager determines the actual text displayed in each interaction and was based off of relational communication and relational agent literature. Figure 3-5 shows the typical sequence of dialogue states that the system presents to the user during each interaction session for the responsive condition. In the non-responsive condition, the relational response is removed. Each interaction begins with a greeting, followed by a question that determines if this is a good or bad time to interrupt the user. If it is a bad time, the system returns to the default status screen. If the user indicated that it is a good time, the system asks a stress-related question and allows the user to enter his current activities through the activity panel (described in more detail in the following section). Depending on the user's answer to the stress-related question, the Dialogue Manager will choose a different response to address the user's stress levels. The relational response is followed by a thanks message and then returns to the default status screen. In the non-responsive condition, the stress-related question is followed directly by the thanks panel. Figure 3-6 shows a sample relational interaction.

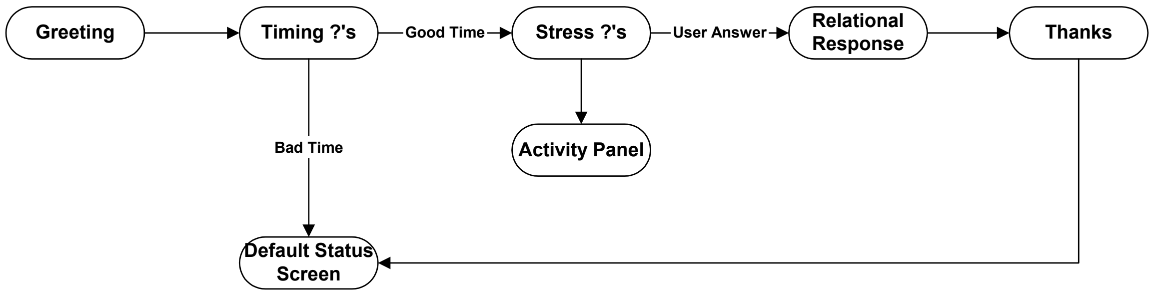


Figure 3-5 Interaction Transition Network for Responsive Condition

To support the evaluation in the following chapter where users interacted with the PMobile system for eight to ten days, the Dialogue Manger was built to provide daily variability in the method of asking the user for time and stress-related annotations (see Appendix B for a full set of dialogue scripts). Each transition to the next state in the interaction network would select question text from the set of the possible dialogues in the next state. The greeting set consisted of nineteen different ways to greet the user, with some specific to time of day (i.e. "Good Morning"). The timing set consisted of sixteen regular questions, with two additional trigger time questions from location and heart event. There were eleven possible stress-related questions and a total of twenty-six different possible relational responses depending on user stress level. Each stress question had five unique answers that were mapped to the specific question. The thanks set consisted of fifteen different ways of thanking the user for annotating or giving feedback about the annotation process. In total, there were 1,467,180 possible different interactions that the system could use to solicit annotations from the user and maintain variability throughout the entire evaluation period.

```
S: Morning, Jane!
S: Do you have a minute?
U: Yes.
S: You know the drill -- feeling stressed?
U: Its there - but not the worst.
S: Wish it was better.  Hope things start looking up.
S: Thanks so much for all your input.  I hope I haven't been too frustrating.
```

Figure 3-6 Sample Relational Interaction

3.2.5 GUI Layer

The graphical user interface (GUI) layer shown in Figure 3-7 is used to obtain user input and give feedback to the user. There are six main GUI panels that are used by the PMobile system: the default status screen, the mute screen, the diagnostic and feedback panel, the annotate panel, the activity panel, and the question panels. The design of the GUI panels is based off of the GUI in the CAES system. Screenshots of the GUI panels are shown in Figure 3-8.

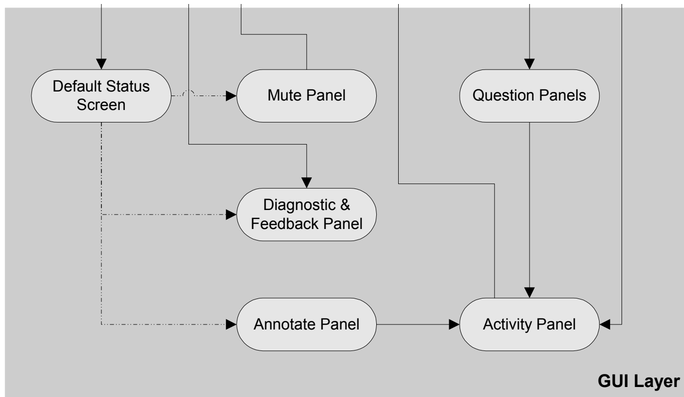


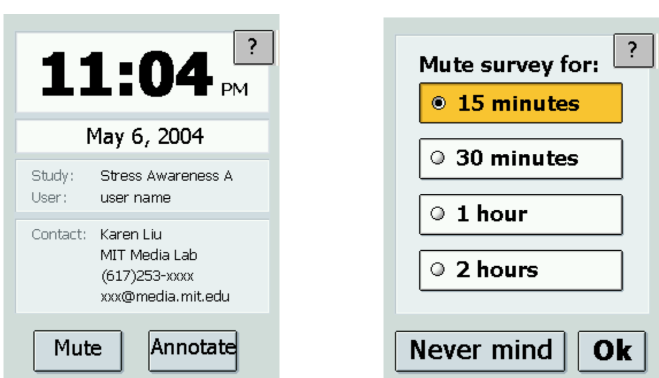
Figure 3-7 GUI Layer

Default Status Screen

The default status screen is always shown when the PMobile system is running, unless the user has initiated an annotation session, has selected the diagnostic and feedback panel, or if the system has initiated an interaction. Drawing from a user information database that contains the study name, study condition (not shown to users), and the experimenter's contact information, the default screen dynamically displays this information. It also dynamically updates the current time and date. From the default status screen, users can select to mute the system, annotate events that might be interesting to them, or check if the sensors are properly connected by viewing their physiological information in real-time.

Mute Panel

The mute panel allows the user to temporarily suspend audible interruptions from the system. The user can select to mute the system for fifteen minutes, thirty minutes, one hour, or two hours. Any mute time selection information is sent to the Interaction Engine to adjust the timer for scheduled annotation sessions.



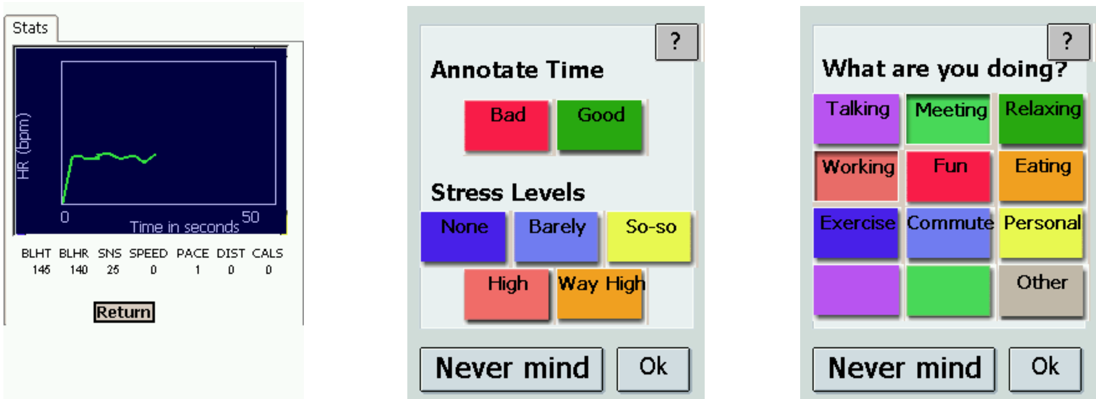


Figure 3-8 GUI Screenshots

(top row) Default Status Screen, Mute Panel,

(bottom row) Diagnostic and Feedback Panel, Annotate Panel, Activity Panel

Diagnostic and Feedback Panel

Using data from the Data Collection Platform, the Diagnostic and Feedback Panel graphs a user's instantaneous heart rate in real-time and displays accelerometer information whenever the "?" button is pressed.. This panel also allows a user to diagnose if the sensors are properly functioning throughout the day.

Annotate Panel

The annotate panel allows a user to indicate what they consider to be interesting events related to their current stress level or activity. Users can also annotate with short audio recordings at any time by pressing and holding down the audio button on the left side of the iPAQ.

Activity Panel

The activity panel was designed to allow users the shortest possible way to annotate their current activities. An activity survey was conducted with four subjects to determine the most useful initial set of activity categories. Each subject was asked to write down their daily activities and then place them into discrete activity categories (i.e. "walking to school" -> Commute, "brushing teeth" -> Personal, "writing a paper" -> Working). The activity categories that all four subjects agreed upon became the initial activity set that was used on the activity panel. These categories included: commuting, relaxing, personal, working, having fun, eating, exercise, meeting, and talking.

Users were allowed to select multiple categories during one annotation session for overlapping activities. More commonly used activities were moved to the top of the panel for easier access to them. The "other" button allowed users to create new activity buttons with categories that were not originally listed.

Question Panels

The question panels had a different text panel for each state in the Interaction Transition Network shown earlier in Figure 3-5. Dynamic buttons were used to select answers to questions.

3.2.6 Analyzation and Visualization Tools

Visualization tools were developed in Matlab to give users access to their health information in a way that visually correlates their activity and stress annotations with their physiological data. The goal here is to provide useful feedback that would allow users to reflect upon, explore, and better understand their own stress and heart patterns over the course of eight to ten days. One example of the raw inter-beat intervals obtained by the PMobile system is shown in Figure 3-9. Converting the IBIs to instantaneous heart rate results in the plot displayed in Figure 3-10. Since the data from the heart strap was often very noisy – noise could be introduced by movement of the strap against the person's skin, a bad connection, interference from muscle movement or respiration, or various other factors – a nearest neighbor thresholding algorithm (see Appendix C) was used on the data to filter noisy values. The filtered HR is also shown in Figure 3-10.

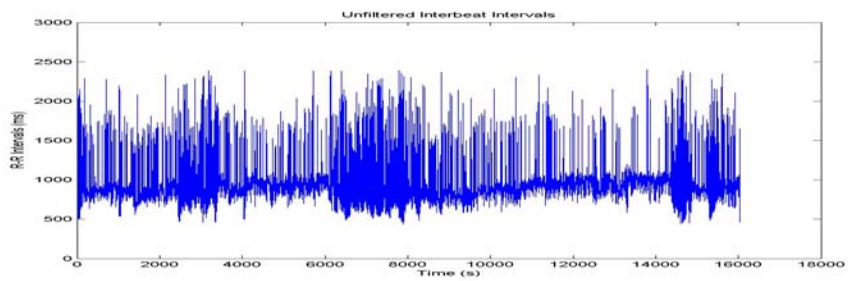


Figure 3-9 Plot of Raw Inter-Beat Intervals

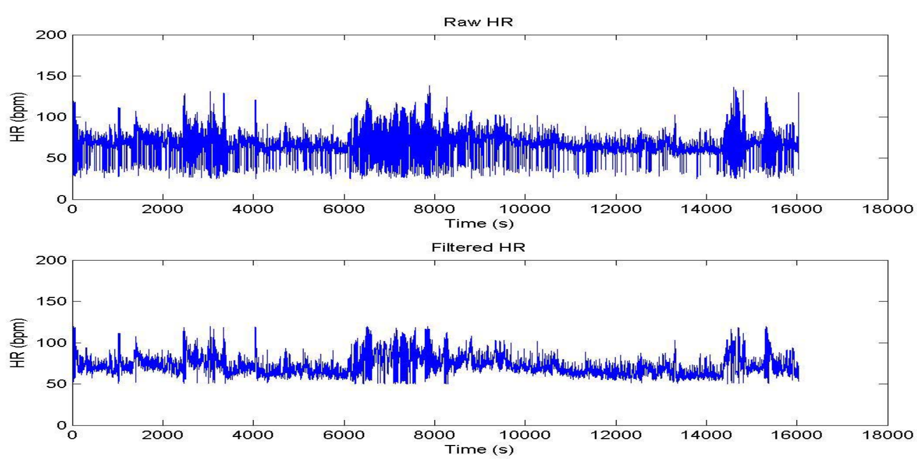


Figure 3-10 Plot of Raw and Filtered HR

Visualizing Stress

Although there is no definitive, non-invasive method of directly measuring stress, heart rate variability (HRV), which is calculated from the EKG, can be used as an indicator. HRV varies not only with stress, but also with physical fitness and age (Umetani 1998). Tending to be greatest in those who are younger, more physically fit, or relaxed, heart rate variability, in general, decreases with age, with declining fitness, and with stress.

HRV is a form of sinus arrhythmia that directly reflects bodily functions, and is typically measured from the power spectrum of the inter-beat intervals. This usually involves windowing the ECG, detecting the beats and computing the IBIs. From this, the spectrogram of the time series of the IBIs is computed and divided into low-, mid-, and high-frequency bands, which separates the relative influences of the baroreflex as well as the parasympathetic and sympathetic nervous system activation (McCraty, Atkinson et al. 1995). This proposed measure for stress uses a new algorithm (Qi, Minka et al. 2002), developed by Yuan Qi at the MIT Media Lab, which computes spectral analysis for non-stationary, unevenly sampled data by using a Kalman filter to jointly estimate all spectral coefficients instantaneously. After obtaining the spectral coefficients, the entropy of the result is used as a measure for stress. Figure 3-11 shows the spectrogram from this algorithm.

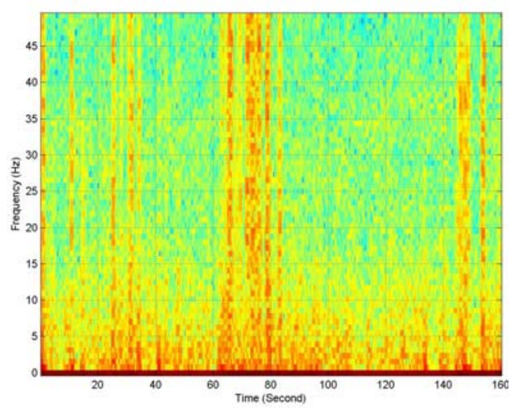


Figure 3-11 Kalman Spectrogram of One Day

Radial Plot

In order to visualize stress and heart data with the annotations for each day, a radial plot (Hirzel 2002) was used in order to visually associate the data with time (i.e. clock). In the radial plot, the location of each point uses an angle and a radius. The angle is given in time values (minutes from the origin) and the radius is given by either heart rate or the entropy measure of stress, depending on what was selected to be displayed. "Stress" was calculated using the

Kalman spectral estimation algorithm followed by computing entropy. Source code of the radial plot can be found in Appendix C.

Annotations were first converted to regular expressions and then plotted on the radial plot with the symbol '*'. Each '*' could be selected and the corresponding annotation in text would be displayed in the text box above the graph to allow for a real-time exploration of stress, heart rate, and activity. Figure 3-12 shows multiple days of heart rate data from multiple subjects. Figure 3-13 shows a single day plot of instantaneous heart rate and Figure 3-14 shows a single day plot of spectral entropy, the proposed measure for stress.

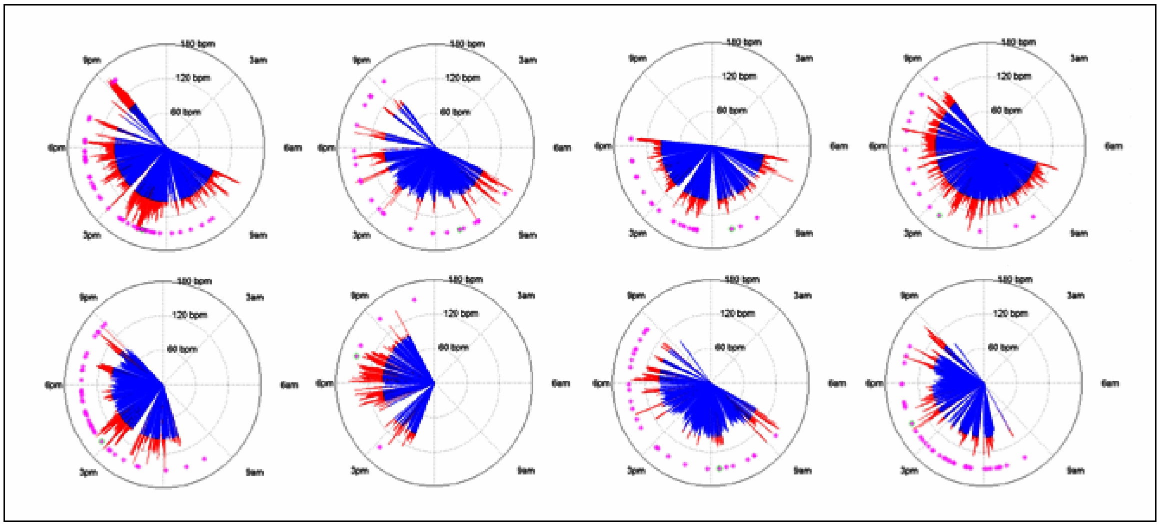


Figure 3-12 Radial HR Plots of Multiple Subjects

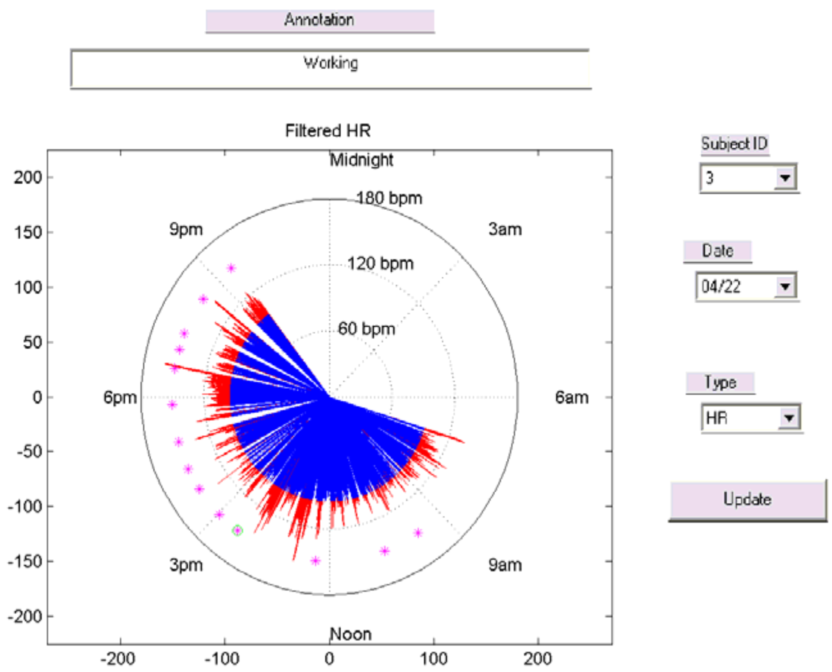


Figure 3-13 Single Day of Heart Data in Radial Plot

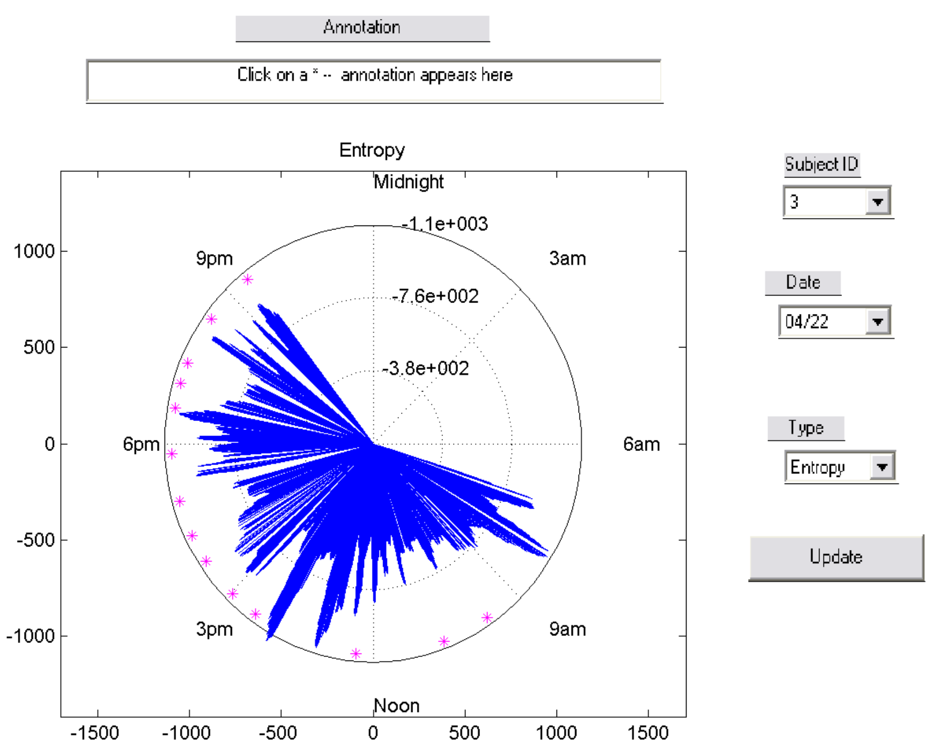


Figure 3-14 Single Day of Spectral Entropy in Radial Plot

Chapter 4

Exploring Stress and Interruptions

This chapter presents an evaluation of the system developed in Chapter 3 where users collected and annotated their stress and activity information each day for eight-ten days. The experiment is intended to explore questions such as *"Is stress information useful to learning when to interrupt? When would it be useful and what can we learn from it?"* and to investigate whether a system that uses relational and attentional strategies in a task that involves a large number of interruptions will be less frustrating and more enjoyable to use.

4.1 Introduction

The evaluation of the PMobile system – known as the "Stress Awareness Survey" to users – was designed to evaluate two different systems on a group of subjects for two weeks. Each subject interacted with both systems for four days and was led to believe that they would choose which system to work with for an additional four days. In order to account for an order effect that might be introduced depending on which system the user interacted with first, subjects were randomly selected to start with either the responsive system or the non-responsive one. Both systems employed minimal relational techniques (e.g. social greeting, friendly); however, only one system responded directly to a user's stress levels with empathetic responses and adjusted the timing of the interruptions by triggering on change in location and interesting heart events. Table 4-1 shows a comparison of the two systems.

Table 4-1 Comparison of System 1 and System 2

	Minimal, but relational	Responsive to stress and interruption-sensitive
System 1 (Non-Responsive System)	Y	N
System 2 (Responsive System)	Y	Y

4.1.1 Hypotheses

The hypotheses of this experiment include:

- H1: Subjects will find the responsive system to be less disruptive and frustrating to use and will have a better user experience while using the responsive system.
- H2: Subjects will choose to continue working with the responsive system.

4.2 Experimental Method

Table 4-2 gives and overview of the experimental protocol used.

Table 4-2 Overview of Experimental Protocol

Day	Procedure
-	Subjects recruited via email.
1	Subjects come into the laboratory for a set-up session. They sign a consent form, are asked to use the system for three 4-day sessions, given a sensor system with take-home instructions, and given a questionnaire for obtaining base-line stress levels, demographic information, and personality information. It is explained that subjects will be using one system for session one, another system for session two, and they will be able to decide which system to use for session three.
2-5	Subjects use the PMobile system for session one and fill out end-of-day questionnaires. Some subjects are in the responsive condition and some subjects are in the non-responsive condition.
6	Subjects come into the laboratory to download data and switch batteries in their sensors. All subjects in the responsive condition switch to the non-responsive condition and vice versa. Subjects are told that they are being switched to a new system and were shown radial plots of their data without annotations. No evaluation questions were asked at this stage.
7-10	Subjects use the system for session two and fill out end-of-day questionnaires.
11	Subjects come into the laboratory to download data and for the final lab session. They

	are given the evaluation questionnaire and given time to explore their data on radial plots. At the end of the questionnaire, they are told that the study is now over and that they do not have to use the system for the third session. Subjects are debriefed and compensated.

4.2.1 Subjects

Subjects were recruited via email solicitation and postings on public message forums. Seven subjects – four female and three male – participated in the user study. Due to the limited number of sensor systems available, the study was run in two waves – the first with four subjects, and the second with three subjects. Each subject committed to wear a heart strap, accelerometer, and pedometer, to place two location beacons in different locations (i.e. home and office), and to carry around the iPAQ from 9:30am to 9:30pm each day for two weeks. Subjects received either a movie ticket or a gift certificate for a local coffee shop for each laboratory visit and $75 cash upon completion of all tasks in the study. Table 4-3 shows the breakdown of subjects by condition and gender. The mean age of subjects was 24.29 with a standard deviation of 2.36. Only two subjects were MIT students, the remaining five were graduate students from other institutions or working in industry.

Table 4-3 Breakdown of Subjects by Condition and Gender

	Session 1	**Session 2**	**Gender**		**Total**
			Male	**Female**	
Condition	**Responsive**	**Non-responsive**	3	2	**5**
	Non-responsive	**Responsive**	0	2	**2**
Total			**3**	**4**	**7**

4.2.2 Apparatus

The experiment uses the PMobile software system described in Chapter 3. Each subject was also given a sensor system consisting of one heart strap, one accelerometer, one pedometer, one BodyLan Hub, one iPAQ, and two location beacons.

4.2.3 Procedure

During the first laboratory meeting, subjects were told that the overall purpose of the study was to investigate people's stress patterns in natural activities and collect stress and activity information for developing computer algorithms to recognize patterns from sensors. They were asked to sign a consent form and the renumeration procedure was explained. Subjects were then shown how to put on the sensors, were given take-home instructions, and were told to fill out end-of-day logs each day. Subjects were told that they would be asked to use two different systems -- system 1 for one four-day session, system 2 for another four-day session, and the system of their choice for the last four-day session. Subjects did not know which system, responsive or non-responsive, they were using. Finally, subjects were given a questionnaire (see Appendix A) for obtaining base-line stress levels, demographic information, and personality information.

Each morning, subjects would put the heart strap around their chest and use the velcro band to put the accelerometer and pedometer on each ankle. Subjects used either the responsive or non-responsive PMobile system for four days (session one) and filled out the end-of-day questionnaires online or on paper each day.

At the end of the four days, subjects came into the laboratory to download their data and switch the batteries in their sensors. All subjects that were in the responsive condition were switched to the non-responsive condition and vice versa. Subjects used the system for four more days (session two) and filled out end-of-day questionnaires.

At the end of session two, subjects came into the laboratory to download their data and for the final lab session. They were first given time to explore their data with clickable annotations on radial plots. When finished, they were given an evaluation questionnaire (see Appendix A). At the end of the questionnaire, after each subject had selected which system they would prefer to use for session three, they were told that the study was over and that they did not have to continue using the system. Subjects were then told the goals and design of the study, which condition they were in, and compensated for their participation.

4.2.4 Measures

Besides evaluation questionnaires and qualitative interviews, there are two quantitative measures that the study used to evaluate the system – self-report questionnaires and behavior measures.

Questions such as "In general, how disruptive do you feel the timing of the interruptions was?" and "To what extent would you like to continue working with the Stress Awareness System?" were asked on a 7-point Likert scale.

Another measure that was used was the *relative subjective count (RSC)*. Relative subjective count is adapted from relative subjective duration (Czerwinski, Horvitz et al. 2001) – a proposed metric that takes the user's estimated time to complete a task divided by total time to complete the task as an implicit probe for measuring user frustration or satisfaction. In this study, the user's estimated number of interruptions (collected during each end-of-day log) divided by the actual number of interruptions was used as a measure for probing user frustration. If the subject greatly overestimated the number of interruptions, they were considered to be more frustrated than if they underestimated the number of interruptions.

Since subjects were led to believe that there were three sessions in the study, the strongest behavior measure for evaluating user preference would be that the user chooses to work with the responsive and interruption-sensitive system for the final session.

4.2.5 Anomalies

Two days after the subjects who used the responsive system first began it was discovered that there was an unusually high number of interruptions from the system. It was discovered that there was a bug in the location algorithm, where the system was triggering on change in power level rather than actual change in location ID's. Only the subjects who used the responsive system first in the first wave of the study (subject 1 and subject 3) were affected, so a second wave of three additional subjects were run in the responsive, non-responsive condition.

4.3 Results

Quantitative results were analyzed using one-tailed, two-sample, t-tests with a 90% confidence interval on each condition and system. After subjects had used both systems and before starting the third session, they were asked to evaluate the system they used in the first session and the system they used in the second system (see debrief evaluation in Appendix A). Figure 4-1 shows the system evaluation for both the responsive system and non-responsive system with mean and standard deviation bars. Since the location trigger bug discussed earlier interrupted subjects due to an inaccurate trigger, the answers from subject 1 and subject 3 were removed from this analysis as their perception of the responsive system was most likely affected by the number of interruptions. Subject 4 also received a high number of interruptions; however these were a result of numerous heart event triggers due to body weight and a new exercise program the subject had entered, therefore, subject 4's data was included. Figure 4-2 shows the results with all subjects included and with subject 1, 3, and 4 removed as a reference to what subjects who received a normal amount of interruptions rated.

For the question, "In general, how disruptive do you feel the timing of the interruptions were?", there was no significant difference to how the subjects rated the systems. In fact, considering the disruptive nature of the task, both systems were rated as quite disruptive.

Subjects rated that the responsive system was significantly less stressful to use than the non-responsive system, t(8) = 1.5, p = .09. Subjects reported that they felt that the responsive system was significantly more responsive to their stress than the non-responsive condition, t(8) = 1.62, p=.07.

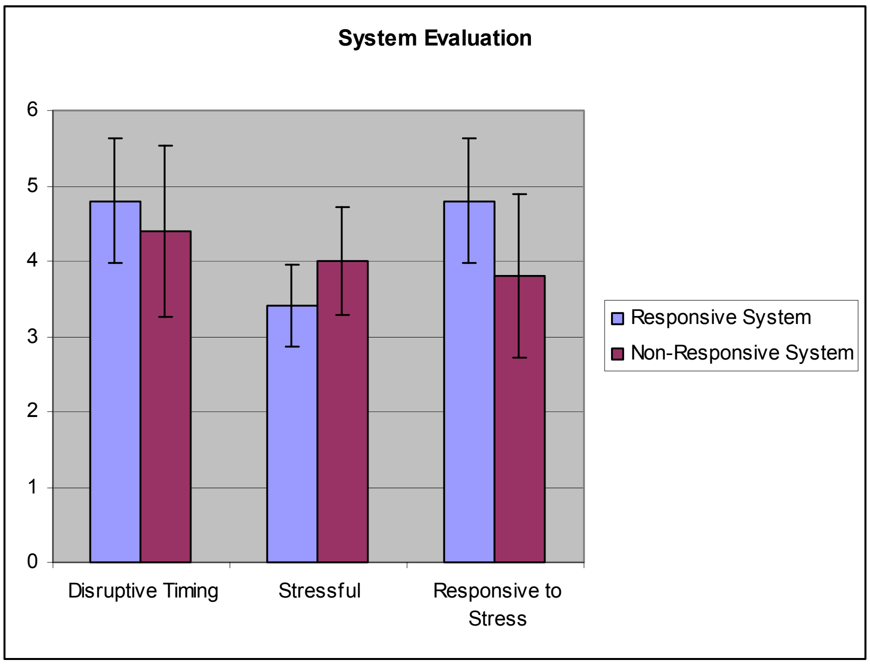


Figure 4-1 System Evaluation (minus subject 1 and 3)

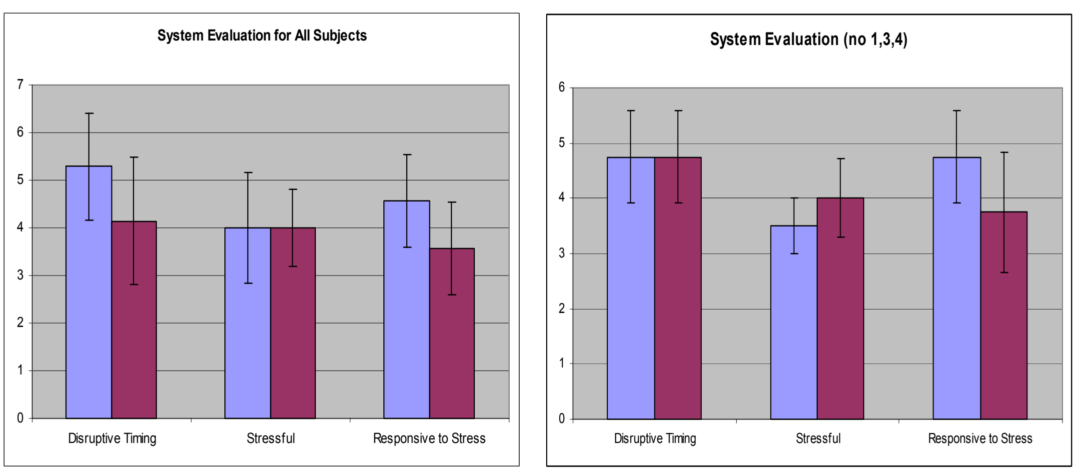


Figure 4-2 System Evaluation for All Subjects (left)
System Evaluation (minus subject 1, 3, 4) (right)

Users were also asked to answer a series of questions based on their experience with the stress awareness study overall (see Appendix A). Figure 4-3 shows the overall experience evaluation by condition. The hypothesis here is that the subjects who ended with the responsive system would *remember* having a better experience overall even if in actuality they didn't (Redelmeier and Kahneman 1996). Subjects who ended with the responsive system rated that their desire to continue with the stress awareness system was significantly higher than subjects who ended with the non-responsive system, $t(5)$, $p = .0015$.

In general, subjects in both conditions felt that the charts were useful for reflecting and understanding more about their heart and activity patterns. One subject commented that the radial plots were more difficult to read than a linear plot, since the radial plot used a 24 hour time window, instead of the typical 12 hour window typically found in the United States. Subjects who ended with the relational system rated that the sensors were significantly more comfortable, $t(5)$, $p = .07$ (however this could also be due to the fact that all subjects in the N, R condition were female). There was also a trend towards significance that the device did not increase their stress levels as much subjects in the other condition, $t(5)$, $p = .13$. After being told that the study was ending early, each user was asked "How do you feel about the study being completed?" There was no significance in how the users responded, although, in general, users with the responsive system answered rather neutrally, whereas subjects who last used the non-responsive system were much happier that the study was completed. These results, although shown with a very small set of subjects, show interesting trends towards significance.

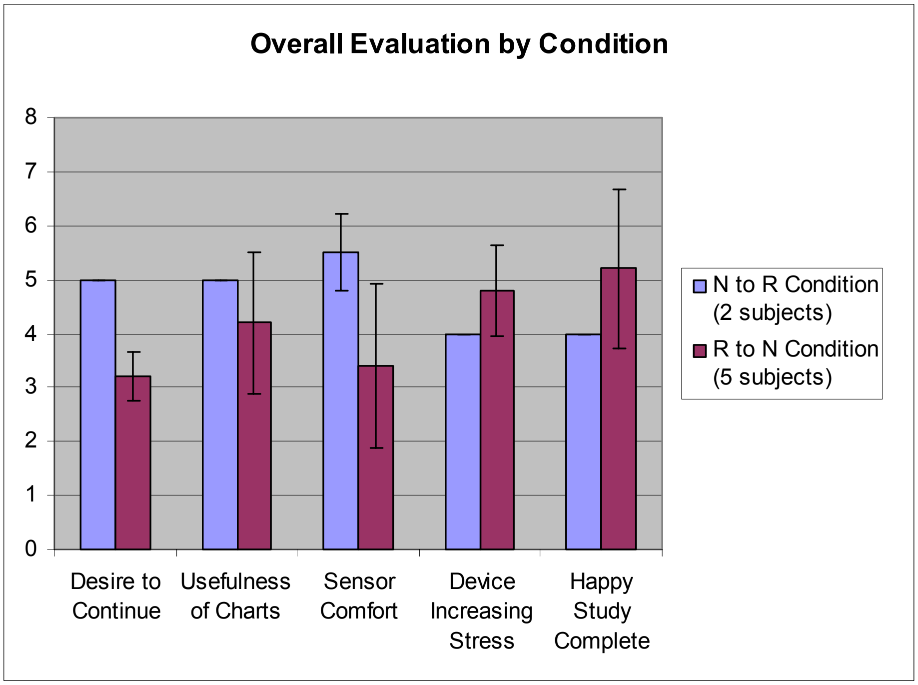


Figure 4-3 Overall Experience Evaluation by Condition

To measure daily perceived frustration from interruptions, each user was asked to fill out their interrupt estimate in the end-of-day logs each night. However, it was not surprising to find that subjects often forgot to fill out the log or lost their paper logs. Since the survey ended at 9:30pm each night, subjects may not have been around a computer or their paper logs when they system told them that the survey was over for the day and may have forgotten by the time they got home to fill out logs. Table 4-4 shows the results of the relative subjective count for days that had an interrupt estimate and data available. Low RSC is believed to correlate to low user frustration, while high RSC is believed to correlate with high user frustration. Table 4-5 shows the total interrupts for each day and the average interruptions for each system type. The average number of interrupts for each type of system is shown, as well as the average number of interrupts without subjects 1 and 3, and without subjects 1, 3, and 4 since those subjects had a particularly high number of triggered interruptions. The two systems were designed to interrupt users, on average, an equal amount of time. Annotations that the user-initiated were not included in the interruption count.

Table 4-4 Relative Subject Count Assessment for All Subjects

User ID	System	Actual Interrupt	Interrupt Estimate	RSC
1	R	4	5	**1.25**
	R	27	20	**0.74**
	N	5	12	**2.40**
2	N	16	20	**1.25**
	N	16	20	**1.25**
	R	17	10	**0.59**
	R	13	7	**0.54**
	R	12	10	**0.83**
3	R	35	40	**1.14**
	R	22	16	**0.73**
	R	58	30	**0.52**
	R/N†	26	32	**1.23**
	N	17	20	**1.18**
	N	11	20	**1.82**
4*	N	5	6	**1.20**
	N	17	20	**1.18**
	N/R	57	40	**0.70**
	R	58	30	**0.52**
	R	33	25	**0.76**
5	R	13	10	**0.77**
	N	9	6	**0.67**
	N	9	15	**1.67**
6	R	12	7	**0.58**
7	R	9	4	**0.44**
	R	11	7	**0.64**
	R/N	19	7	**0.37**
	N	13	6	**0.46**

† Subject used one system for part of the day and switched to the other system for the other part of the day.
* The actual interrupt was especially high for subject 4 due to numerous heart event triggers as a result of body weight and a new exercise program the subject had entered.

Table 4-5 Total and Mean Interrupts for Each Day

User ID	System	Actual Interrupt	User ID	System	Actual Interrupt
1	R	4	5	R	13
	R	8		R	1
	R	27		R/N	2
	R	13		N	9
	R/N	n/a[†]		N	11
	N	n/a[†]		N	15
	N	4		N	9
	N	5	6	R	12
	N	10		R	8
2	N	16		R	8
	N	10		R	9
	N	16		R	10
	N	5		R/N	12
	N/R	14		N	8
	R	17		N	8
	R	13	7	R	5
	R	12		R	9
3	R	8		R	10
	R	35		R	11
	R	22		R/N	19
	R	58		N	11
	R/N	26		N	13
	N	3		N	9
	N	17	**Avg R (all)**		**19.66**
	N	11	**Avg N (all)**		**11.22**
	N	n/a[†]	**Avg R (no 1,3)**		**18.81**
4	N	5	**Avg N (no 1,3)**		**11.35**
	N	19	**Avg R (no 1, 3, 4)**		**10.13**
	N	17	**Avg N (no 1, 3, 4)**		**10.81**
	N	13			
	N/R	57			
	R	58			
	R	60			
	R	33			
	R	25			
	R	10			

[†] Data was lost this day as a result of technical problems

Finally, the strongest behavior measure evaluated was that subjects would actually choose to continue using the system that they had a better overall experience with. Table 4-5 and Figure 4-4 show the final system selections made for each user. Subject 3, one of the users with the location bug responsive system, initially chose the non-responsive one to continue with. However, in the debrief when told that there was a bug in the first system that caused increased interruptions, she immediately switched her selection to the responsive system which she said she had a better experience with overall, but the amount of interruptions caused her to choose the other system. Subject 1 had the location bug in his responsive system and subject 6 said that she chose her system because the interruptions were more predictable.

Table 4-6 Subject System Type for Each Session

User ID	Session 1	Session 2	Session 3 Selection
1	Responsive†	Non-Responsive	Non-Responsive
2	Non-Responsive	Responsive	Responsive
3	Responsive†	Non-Responsive	Responsive
4	Non-Responsive	Responsive	Responsive
5	Responsive	Non-Responsive	Responsive
6	Responsive	Non-Responsive	Non-Responsive
7	Responsive	Non-Responsive	Responsive

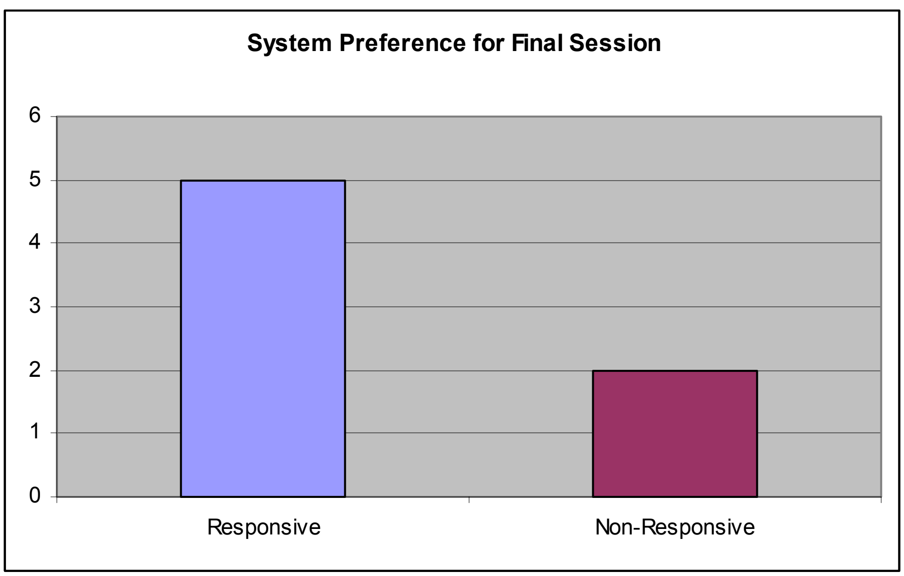


Figure 4-4 System Preference Results for All Subjects

† Used system with the location bug

4.4 Discussion

Although results support the hypothesis that subjects would choose to continue interacting with the responsive system, it was unclear if this was a result of the adaptive relational responses or whether they actually preferred the timing of the interruptions more. It seems from the user data that subjects consistently rated the system that triggered on location and heart information as more disruptive in terms of timing. Since the system triggered a question immediately after a return to normal heart rate values after detecting elevated heart information, it is plausible that a system would be less disruptive if there was a greater delay after the detection of exertion or psychological stress to interruption time. If this is the case, than there is an even stronger reinforcement that designing systems that are relational and address a user's affect can lead to a better experience overall, even when the system might be extremely disruptive. This is not to say affect-sensitive systems should be used to disguise poorly designed software, but rather used as a tool to enhance user experience and facilitate persistence in a task.

In addition, most subjects encountered some technical difficulties with the sensors, which may have also affected results. Almost every subject during the ten days encountered at least one message that the BodyLan Hub was not connected properly to the iPAQ. To improve the connection, the BLH was firmly attached to the back of the iPAQ which solved many of these disconnection problems. One subject immersed the heart strap in water after the first day which caused the battery in the heart strap to corrode. Another subject encountered an unknown error with the entire iPAQ File Store where the data and program was stored. The iPAQ was sent to HP technical support to attempt to recover the data, but the files were corrupted and three days of data were lost. Many subjects often forgot the iPAQ when they were taking short trips (i.e. to the restroom) or left the range of the BLH (i.e. bedroom to living room in a house), thus their data was discontinuous and sometimes very limited.

Although there were numerous technical difficulties, a novel, annotated database has been collected that will be useful to study correlations between stress on the heart and activities, leading to a deeper understanding of the effects of positive and negative stress on the heart. The database includes accelerometer, pedometer, and inter-beat interval data, as well as location ID tags from the location beacons for seven subjects over eight-ten days with corresponding stress, activity, and timing annotations. The interruption timing annotations also provide a useful preliminary database for developing machine learning algorithms for understanding how stress might interplay on interruptibility, as well as providing a database to investigate the changes in physiology before and after the system interruptions and relational response.

4.5 Summary

This chapter presented an evaluation of a system which uses stress information to determine interruption times, and in addition, uses affect-sensitive dialogue to directly respond to a user's stress to facilitate a less frustrating and more enjoyable experience over time. This type of responsive system did result in a significant decrease in how stressful the system was on users, and five out of seven of the subjects chose to continue working with the responsive system when given an option between versions. There is still a significant amount of work to be done in the robustness and reliability of the sensor hardware, as well as developing algorithms to understand the physiological signature of stress. Returning to the question of whether stress information is useful to learning about interruptions, this study has shown that immediately triggering interruptions based on stress may lead to more disruptive systems, however, designing systems that recognize stressful events and respond directly to a user's affect can lead to a better user experience overall.

Chapter 5

Conclusion

Overall, this thesis has three main contributions: 1) a new system for gathering annotations useful for studies of stress and interruptibility, 2) new insights into the value of using relational and attentional strategies in interactive health monitoring systems, and 3) a novel, annotated database useful to study correlations between stress on the heart, activities, and interruptions.

Chapter 3 presented an affect and interruption-sensitive system that allows for continuous, real-time user annotation of stress, activity and timing information through text and audio input on a mobile platform. The platform supports continuous, wireless, and non-intrusive collection of heart signal data, accelerometer, and pedometer information, as well as automatic labeling of location information from context beacons. This system is the first of its kind to be affect and interruption-sensitive: it uses physiological data to adjust the timing of interruptions, and it adaptively responds with dialogue and relational strategies that specifically address the user's stress levels and the disruption the device may be incurring upon the user.

Chapter 4 presented an evaluation of the system which demonstrates that designing platforms that are relational and responsive to a person's affect can facilitate a less frustrating and more enjoyable experience over time, even in tasks that are highly disruptive. The study was conducted with seven subjects who used either the responsive or non-responsive system for four days, then used the opposite system for another four days, and finally, were asked to choose which system to continue interacting with for the last four days. Not only did the subjects subjectively rate that the responsive system was significantly less stressful on users, but the relative subjective count for each day also supports the hypothesis that users were less frustrated using the responsive system. This study has repeated results shown from relative subjective duration and added to the validity that this might be new measure to probe user satisfaction in human-computer interaction. As the strongest behavior measure for evaluating the two systems, five out of seven of the subjects chose to continue working with the responsive system. This study has shown that immediately triggering interruptions based on stress may lead to more disruptive systems; however, designing systems that recognize stressful events and respond directly to a user's affect can lead to a less stressful and better user experience overall.

Finally, another contribution of this thesis is a novel, annotated database that will be useful to studying correlations between stress on the heart and activities, leading to a deeper understanding of the effects of positive and negative stress on the heart. The interruption timing annotations also provide a useful preliminary database for developing machine learning algorithms for understanding how stress might interplay with interruptibility.

5.1 Future Work

There is still a significant amount of work to be done and data to be gathered before truly understanding more about stress, the physiological signals involved in its expression, and how our emotions might impact our heart health. The database should be analyzed in greater detail to probe and remove any potential biases because of the probabilistic dependencies between good interruption times and user stress states. One potential way of dealing with potential biases would be to compare a user's answers when prompted at predicted good or bad times with a user's stress answers from random sampling.

Clustering of heart information with stress and activity labels should be used to study the patterns and correlations between our activities, stress, and interruptibility in order to build more reliable models for timing and availability. Additional features, such as calendar information, time of day, and accelerometer data, could be used. In addition, there is more work to be done in developing better, more reliable models of stress. Using combined heart and accelerometer information can separate physical exertion from cognitive stress. In addition, machine learning techniques, in tandem with user feedback, should be developed to allow online learning of activity labels and predictions of stress labels to facilitate the data annotation process.

This thesis has shown promising results for affect and interruption-sensitive devices, however, these results were on a small set of people and used only 90% confidence intervals for significance. The Stress Awareness Study should be repeated with a larger sample size and over a longer period of time. Another important area of future work includes separating out the social-emotional relational response versus the timing of the interruptions in order to understand the influence of each factor separately, as well as together.

Finally, these strategies could be particularly powerful with relational agents that motivate behavior change (i.e. at-the-moment interventions, tips from a mobile exercise trainer, notifications to take medicine) where the information that the device is interrupting the user to deliver is of greater importance.

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Appendix A: Experimental Protocol for Stress Awareness Study

Experimenter's Script

PREPARING HARDWARE

1. In **Settings->Personal->Sounds&Notifications** – Enable sounds for Events and Programs (make sure that program notifications are turned off).
2. In **Settings->System->Power** – Uncheck both On battery power turn off and On external power turn off.
3. In **Notes->Options** – Set Audio Notes to stay in current application.
4. Each sensor set consists of: 1 iPAQ, 1 Pulser, 1 Footpod, 1 Pacer, 2 Location Beacons, and 1 BLH.

PRIOR TO LAB SESSION 1

5. Locate subject folder.
6. Retrieve from folder the following: **Informed Consent Form, Initial Questionnaire, Instructions for Use of PMobile System** and **End of Day Questions.**
7. Review computer task to be performed during the lab session, so that you may answer any questions participant may have.
8. Prepare **Hardware** (see above section).
9. Assign a subject number to participant and record participant's information on Master Subject List.
10. Remove the palmtop from the shelf that corresponds to the subject number assigned to the participant and sign the iPAQ out to the participant on the **Master Subject List (e.g., subject 1 must get system 1, subject 2 must get system 2, etc.)**.
11. Check the battery levels in the palmtop.
12. Find the participant's folder in the designated drawer, once you have assigned the participant's subject number. All paper work will be contained in the folder as it becomes available.

EXPERIMENTER'S SCRIPT

1. *"Thank you for coming today. My name is _____ and I will be your experimenter over the next 2 weeks of this study. The overall purpose of this research is to investigate people's stress patterns in natural activities."*
2. Have participant read and sign **Informed Consent Form**. Also get participant's telephone number and email address, and record them on photocopy of participant's ID and place them in their folder.
3. **Review the procedures** for use of the palmtops with the participant. *"I will be giving you a heart strap sensor to collect information regarding your heart, an accelerometer to sense motion, speed, and distance, a pedometer to track number of steps, and two location beacons that you can place anywhere you want to give the system a better idea of where you are. I will also be giving you an iPAQ that will wirelessly receive and store the data. The system on the iPAQ will prompt you with beeps throughout the day to ask you questions regarding your stress and your activities. Do you have any questions?"* Answer any questions participant has regarding the iPAQ portion of the study.
4. Describe the **remuneration procedure** to the participant. Important points: (1) Make clear that the participant will be paid $75 for participation in the study, but that such amount will be paid only after full completion of the study. (2) Explain to the participant that his or her data will be checked and he or she will not be paid if his or her responses are random. (3) Explain that the participant will be given a voucher after the experiment. (4) Also explain to the participant that he/she will earn weekly remunerations such as movie tickets or coffee gift certificates for each lab visit.
5. "*I'd like to offer you a spot in the study. But before you accept, I want to explain the position I'm in so you can decide whether or not to enter. Unless you are almost positive that you will be available for the next two weeks, please, please do not enter the study.*

   If you drop out without completing the study, I can't use ANY of your data. So I'll have to replace you with another subject, and I might not be able to find one who can finish on time and only have a certain number of sensor systems. I desperately need to finish this study so I can graduate this spring, which means that I need every subject who enters the study now to finish.

   If you can make two other lab sessions after this one and can use the system for at least 12 days, please sign up. If you have any questions or comments during the study, or if your sensors are giving you trouble, please contact me *right away. I won't be bothered to get calls or emails on the weekend or at night. If there's anything I can do to help you finish the study, I will do it.*

One other important thing is that you not talk to people about the study until after the study is finished. I am experimenting with different techniques for monitoring your stress, and if you talk to someone else in the study it can ruin the results."

6. *"For security purposes, I am going to take a photocopy of your driver's license and/or your MIT ID. You are in possession of MIT property. It is very important that you make every scheduled lab session, or if you can't make it, contact me beforehand. If you don't get in touch with me within 48 hours of the scheduled lab session, I will have to call MIT police regarding the sensors and iPAQ."* It is very important to stress with participants that (1) they are in possession of MIT property. Also (2) stress that if they miss a scheduled lab session in the future, do not get in contact with you beforehand and are out of touch for more than 48 hours, you will have to report to the MIT Police that the palmtop is missing. Make a photocopy of the participant's MIT ID <u>and/or</u> driver's license.
7. Show subject how to put on all the sensors and use the system. *"If you ever wanted the system not to interrupt you for a certain amount of time, you can use this **[show the mute button]** button. You can also use this button here **[show annotate button]** to annotate any activities that may be interesting to you. This button **[show ? button]** allows you to see the sensor data in real-time and to make sure that the sensors are connecting to the system. All of this is described on an instruction sheet that I'm going to give you."* Go through end of day questions and how to restart the program.
8. **Schedule Lab Sessions 2-3-4** with the participant. These sessions should be on the same day of the week as Lab Session 1, for each of the following 4 days after the last lab session.
9. *"Finally, I'd like you to fill out a few questionnaires on the computer. Remember, your responses are completely voluntary. When asked for your USER ID, use the number on the consent form."*
10. *"Thanks for helping out."*

<u>**AFTER LAB SESSION 1**</u>

1. Make sure the data from the computer/paper task completed during the lab session has been properly saved on the computer on which the participant was run.
2. Record that you have saved the data by indicating the date in the appropriate column on the **Saved Data Log**.
3. Make sure that the **Informed Consent Form**, **Questionnaire 1**, and a copy of the participant's driver's license are properly filed in the participant's folder.
4. Make sure that you have reserved all future lab sessions with the participant.

Consent Form

CONSENT FORM
Stress Awareness Survey from Mobile Computer Sensors

You are asked to participate in a research study conducted by Karen Liu from the Affective Computing Group at the Massachusetts Institute of Technology (M.I.T.) Media Laboratory. The results of this study will be contributed to a Master's thesis. You were selected as a possible participant in this study because you are interested in understanding more about the different stress patterns in your own life. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

- **PURPOSE OF THE STUDY**

The purpose of the study is to collect perceived stress and activity information in order to investigate the nature and patterns of stress in people's daily lives. The data collected will be used to develop new algorithms for detecting activity from sensors and identifying stress from physiological signals.

- **PROCEDURES**

If you volunteer to participate in this study, we would ask you to do the following things:

- Attend three 45min. lab sessions where you will be asked to complete a questionnaire about your thoughts, habits, and daily stress levels.

- At the end of the first lab session, the experience-sampling portion of the study will be explained to you. You will be given a palm-top computer that will alert you randomly throughout the day. You will use this computer to record your perceived stress, activities, and whether it was a good time to interrupt you for a 2-week period. Each entry should take less than 2 minutes to complete and can also be initiated by you if there is a significant event that occurs.

- You will be asked to visit the lab three times (two additional times), every four days of the study to (1) up-load your data, (2) change the batteries in the palm-top computer and all mobile sensors, and (3) complete additional laboratory tasks.

- A copy of your MIT identification or driver's license will be taken to ensure the security of the palm-top computer in your possession during the 2-week sampling period. If you miss a scheduled lab session and are out of touch with the experimenter for more than 48 hours after that time, we will have to report to the MIT police that the palm-top computer is missing.

- **POTENTIAL RISKS AND DISCOMFORTS**

The device will need to disrupt you frequently throughout the day in order to gather data. If any discomfort is felt due to the device beeping and interrupting, you can mute the device temporarily or, if the device is causing serious discomfort, put the PDA down, take the sensors off and stop carrying them.

Should you experience ill effects or have questions/concerns regarding the study, please contact the investigators (information listed at the end of this consent form). If you experience any ill effects (either mentally or physically) during or after the study, inform the investigators immediately.

- **POTENTIAL BENEFITS**

Self-knowledge: People often gain valuable and interesting insights into their own experiences through research participation. This study will allow you to become more aware of the stressful areas of your life and how that stress might look on your heart.
Contribution to science: When you participate in research, you have the benefit of knowing that the science you read about is based on real people like you. Like other volunteer activities, you are contributing to the greater community when you volunteer for research. The results of this work may help engineers improve the design of mobile computing devices such as phones and palm-top computers, as well as help numerous researchers design data collection tools to study not only stress, but various human phenomenon.

- **PAYMENT FOR PARTICIPATION**

In exchange for your participation, you will receive $75 ($5 for each day of participation), plus a small remuneration after each weekly lab visit (movie tickets, coffee coupons, etc.). You will be paid the $75 at the end of your 2 weeks of participation. If you choose to terminate your participation before it is complete, you will keep your weekly remunerations, but you will forfeit the $75.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

Data will be collected on the palm-top device and from interviews. The palm-top device will record audio annotations of activities (initiated by you), your responses to questions prompted by the device, accelerometer data (movement), and heart rate.

Each week, the researcher will download the data from the palm-top device and store it on a machine that is only accessed by the researcher.

If audio annotation is the subject's preferred method of annotation, you will have the right to review and edit any annotations prior to downloading the data to the researcher. Only the researcher will have access to these audio recordings and these annotations will be destroyed one year after the completion of the study.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact:

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617-253-6341
kkliu@media.mit.edu
20 Ames St. E15-120g
Cambridge, MA 02139

Rosalind Picard
617- 253-0369
picard@media.mit.edu
20 Ames St. E15-020g
Cambridge, MA 02139

- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

"In the unlikely event of physical injury resulting from participation in this research you may receive medical treatment from the M.I.T. Medical Department, including emergency treatment and follow-up care as needed. Your insurance carrier may be billed for the cost of such treatment. M.I.T. does not provide any other form of compensation for injury. Moreover, in either providing or making such medical care available it does not imply the injury is the fault of the investigator. Further information may be obtained by calling the MIT Insurance and Legal Affairs Office at 1-617-253 2822."

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E32-335, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

____ ______________
Signature of Subject or Legal Representative Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

____ ______________
Signature of Investigator Date

Subject Take Home Instructions

INSTRUCTIONS FOR USE OF PMOBILE SYSTEM

HARDWARE

13. To **start** the system: Click on **Start -> Programs-> PMobile.**
14. To **soft reset** the system: use the stylus to push the small hole under lower right side of the iPAQ.
15. To **recharge** the system: Take the power cable and plug it into the sensor BLH connector (do not remove BLH)

Sensors:

- Heart Strap: Follow the instructions on the Heart Strap Instruction Sheet in your box. Make sure to run water under the two electrodes after the strap is on.
- Dark Gray Device: One click and hold down to start, it will shut down by itself if there is no movement so remember to press once when you start moving. Attach to shoelace or to wire/ribbon around ankle.
- Blue Device: One click to start.
- Silver Device: One click to start (you don't need to touch this sensor again after turning it on).

'?' DIOGNOSTIC SCREEN

1. Click **?** to check if the sensors are working and see your heart in real-time. If the Heart rate sensor is working, you will see a plot of your heart rate.
2. Check throughout the day that your sensors are working correctly by checking that the BLHT, BLHR, and SNS numbers are incrementing. If the **BLHR number stops incrementing, soft reset the iPAQ and restart the program.**
   - BLHT: BLH transmit
   - BLHR: BLH receive
   - SNS: sensor packets
   - SPEED: speed in mph
   - PACE: average pace in m/m
   - DIST: distance traveled in miles
   - CALS: approximate calories burned

ANNOTATION PANEL

1. Select **annotate** at the main menu.
2. Select good/bad timing and stress level. You must make both selections in order to move forward.
3. On activity screen, you can select **more than one activity at a time**.
4. You can select "Other" to add new activities.

Activity Types:

- Commute: Walking, driving, shuttling to and from places, etc.
- Exercise: Sports or working out, etc.
- Fun: Anything that you're having fun in (i.e singing, watching a movie), etc.
- Talking: Socializing, etc.
- Eating: Eating or drinking, etc.
- Working: Studying, writing a paper, coding, etc.
- Personal: Grooming, washing up, getting ready for bed, etc.
- Meeting: In a meeting, etc.
- Relaxing: Quick nap, watching a movie could be here, cooking, etc.

WORKING WITH THE SET INTERACTION

1. Click **mute** on the main menu to suspend the system from interrupting you for a set amount of time.
2. When system beeps, a greeting message appears. **You must click on the screen to continue interaction.**
3. Follow steps to answer questions.
4. To annotate activities, an **"Enter Activities**" button will appear. **Please do this before continuing**.

END OF DAY INSTRUCTIONS

1. The system will alert you when the survey ends each day. This time was set during your first meeting.
2. Take off sensors, but there is no need to shut off the program. It will know when to wake up the next day and when to go to sleep each night.
3. Plug the charger into the BLH power adapter.

4. **Fill out end of day log**. Go to http://18.85.1.97:8080/stress/endDay.jsp and fill out the short form. If you cannot access the internet on any particular day, use the paper End of Day Log for that day.

- **Session Number** is specified on your paper log (1 for first 4 days, 2 for second 4 days, 3 for third four days in study)

Feel free to contact us at any time if you have questions or are having any problems at kkliu@media.mit.edu. There is also a comment/feedback section on the End of Day Log that you can use to report problems, give us feedback, or just say hi.

Questionnaire for Lab Session 1

Thank you for volunteering to participate in this stress awareness study. Please take a few moments to fill out some background information.

---

1. UserID
2. First Name (What you go by)
3. Age
4. Gender — Male Female
6. Education Level — Choose One
7. What is your occupation?

Next

Page 1 of 4

How would you describe your awareness of your daily stress levels?

Very Aware
Aware
Not Aware
Not Very Aware

Not sure

To what extent would you agree with the use of the following words to describe you?

Domineering

Meek

Not Aggressive

Dominant

Self-confident

Forceful

Self-doubting

Firm

Self-assured

Assertive

Timid

Enthusiastic

Cheerful

Extroverted

Introverted

Jovial

Shy

Silent

Undemonstrative

Next

Page 2 of 4

Stress Quiz

Simply answer the questions below to the best of your ability and click the "Calculate Report" button below to tally your answers. You can scroll down to read your report.

1. During the past month, how have you been feeling in general?

In excellent spirits
In very good spirits
In good spirits mostly
I've been up and down a lot
In low spirits mostly
In very low spirits

2. During the past month, has nervousness or your nerves bothered you?

Extremely so, to the point where I could not work or take care of things
Very much so
Quite a bit
Some, enough to bother me
A little
Not at all

3. During the past month, have you been in firm control of your behavior, thoughts, emotions, or feelings?

Yes, definitely
Yes, for the most part
Generally
Not too well
No, and I am somewhat disturbed by that
No, and I am very disturbed by that

4. During the past month, have you felt so sad, discouraged, or hopeless, or have you had so many problems that you wonder if anything is worthwhile?

Extremely so, to the point that I have just about given up
Very much
Quite a bit

Some, enough to bother me
A little
Not at all

5. During the past month, have you been feeling that you are under any strain, stress, or pressure?

Yes, almost more than I can bear
Yes, quite a bit of pressure
Yes, some, more than usual
Yes, some, but the same amount as usual
Yes, a little
Not at all

6. During the past month, how happy, satisfied, or pleased have you been with your personal life?

Extremely happy
Very happy
Fairly happy
Satisfied and pleased
Somewhat dissatisfied
Very dissatisfied

7. During the past month, have you been wondering if you are losing your mind or memory or losing control over the way you act, talk, think, or feel?

Not at all
Only a little
Some, but not enough to be concerned
Some, and I've been a little concerned
Some, and I'm quite concerned
Yes, a lot, and I'm very concerned

8. During the past month, have you been anxious, worried, or upset?

Extremely, to the point of being sick or almost sick
Very much
Quite a bit
Some, enough to bother me
A little
Not at all

9. During the past month, when you woke up, did you feel refreshed and rested?

Yes, every day
Yes, most every day
Fairly often
Less than half the time
Rarely
No, never

10. During the past month, have you been bothered by any illness, physical disorder, pain, or fears about your health?

Yes, all the time
Yes, most of the time
More than half the time
Sometimes
Once in a while
No, never

11. During the past month, has your daily life been full of things that were interesting to you?

Yes, always
Yes, most of the time
More than half the time
Sometimes
Once in a while
No, never

12. During the past month, have you been feeling downhearted and blue?

Yes, all the time

Yes, most of the time
More than half the time
Sometimes
Once in a while
No, never

13. During the past month, have you been feeling emotionally stable and sure of yourself?

Yes, always
Yes, most of the time
More than half the time
Sometimes
Once in a while
No, never

14. During the past month, have you been feeling tired, worn out, used up, or exhausted?

Yes, always
Yes, most of the time
More than half the time
Sometimes
Once in a while
No, never

15. On a scale of 0 to 10 (0 being not concerned or worried and 10 being extremely concerned or worried), how concerned or worried have you been about your health during the past month?

16. On a scale of 0 to 10 (0 being very relaxed and 10 being the extremely tense), how relaxed or tense have you been during the past month?

17. On a scale of 0 to 10 (0 feeling no energy or pep and 10 feeling extremely energetic or peppy), how much energy, pep, and vitality have you felt during the past month?

18. On a scale of 0 to 10 (0 being very depressed and 10 being very cheerful), how depressed or cheerful have you been during the past month?

Make sure you have answered all the questions. Then click on the button below to tally your responses. Your personal report will appear below.

Page 3 of 4

Your Report

This report indicates how well you have been coping with life's stressors. Compare your scores to the recommended scores in each area.

Stress Indicator Scores

Stress Indicator	Your Score	Recommended Score
Freedom from health concern or worry	9	10 - 15
Energy level	6	15 - 20
Satisfying and interesting life	10	7 - 10
Cheerful vs. depressed mood	6	18 - 25

Relaxed vs. tense or anxious	9	18 - 25
Emotional control and stability	15	10 -15
Total Stress Score	55	

Your Total Stress Score

Your total stress score is the sum of your six stress indicator scores. This score indicates how well you have been coping with life in the last month. A score of 81 or higher indicates you are coping well. Scores of 70 or below signify that you are over-stressed. Very low scores (55 or lower) indicate a high stress load (distress) and a need to make changes to decrease your stress load and improve your health. People with very low scores may benefit from consulting with a friend, pastor, counselor, therapist, or doctor about managing stress.
Compare your score to the scores of 6,900 American adults (randomly selected from throughout the United States) who completed this stress evaluation.

Sample Scores from 6,900 People		
Rating	**Scores**	**Percent of People**
Positive well-being	81-110	55%
Low positive	71-80	19%
Stress zone	56-70	16%
Distress zone	41-55	7%
Significant distress	26-40	2%
Severe distress	0-25	<1%

Page 4 of 4

End of Day Log

End of Day Instructions:
1. Soft reset the iPAQ.
2. Power off iPAQ.
3. Charge iPAQ!! Plug power cable into the black box connector to the iPAQ.

UserID

Session 1

Date 05/04/04

Time of Day Start Time of Day End

How many times do you think the system interrupted you today?

How stressed overall in comparison to other days (in general) did you feel today?
Much worse
Worse
About the same
Better
Much better

Comments/Problems:

Submit

Debrief Questionnaire

Evaluation

---

1. UserID

Continue

Page 1 of 7

Evaluation of **Session 1**: Please answer the following questions about the **first** system that you used.

1. In general, how disruptive do you feel the timing of the interruptions were?

   7 (disruptive)
   6
   5
   4
   3
   2
   1 (not disruptive)

2. How stressful has using the system been?

   7 (very stressful)
   6
   5
   4
   3
   2
   1 (reduced stress)

3. How responsive did you feel the system was to your stress?

   7 (Very responsive)
   6
   5
   4
   3
   2
   1 (Not responsive)

4. Are there suggestions or changes that you would make to the system?

5. If these improvements were made to the system, would you still find it as stressful?

   Yes, still stressful.

Not sure.
No, it would be less stressful.

6. Any other comments or feedback on the first system in session 1?

Page 2 of 7

Evaluation of Session 2: Please answer the following questions about the second system that you used.

1. In general, how disruptive do you feel the timing of the interruptions were?

7 (disruptive)
6
5
4
3
2
1 (not disruptive)

2. How stressful has using the system been?

7 (very stressful)
6
5
4
3
2
1 (reduced stress)

3. How responsive did you feel the system was to your stress?

7 (Very responsive)
6
5
4
3
2
1 (Not responsive)

4. Are there suggestions or changes that you would make to the system?

5. If these improvements were made to the system, would you still find it as stressful?

Yes, still stressful.
Not sure.
No, it would be less stressful.

6. Any other comments or feedback on the second system in session 2?

Page 3 of 7

Please answer the following questions about your experience with the stress awareness study.

1. To what extent would you like to continue working with the Stress Awareness system?

7 (Yes, very much so)
6
5
4
3
2
1 (No way, I'd be happy to be free)

2. How useful were the charts of your heart activity with your annotations?

7 (Very useful)
6
5
4
3
2
1 (Not very useful)

3. How comfortable were the sensors?

7 (Very comfortable)
6
5
4
3
2
1 (Very uncomfortable)

4. How did you see the device interacting with your stress levels?

7 (Increasing it)
6
5
4
3
2
1 (Reducing it)

5. Which system would you like to use for session 3?

System 1
System 2

6. Why did you choose the system that you did?

6. Any other comments or feedback on the system, sensors, experience, charts, in general?

Page 4 of 7

Thank you for your participation.

The study has now been completed. You will not be asked to complete a third session with the stress awareness system but will receive full remuneration for the time you were originally asked to commit too. In actuality, this study was designed to study interruptions and how that might interplay with stress. After completing this survey, the experimenter will debrief you on the true purpose of the study and the differences between each system, as well as answer any questions you may have.

Continue

Page 5 of 7

1. How do you feel about the study being completed?

7 (Yay! This totally made my day.)
6
5
4
3
2
1 (Super bummed. I'll miss my little buddy.)

Page 6 of 7

That's it! Thanks so much for completing this survey!
Please let the experimenter know that you are finished.

Appendix B: Dialogue Scripts

Greetings	Timing Questions	Stress Questions
Morning, <user name>!	Is this a good time to chat?	How refreshed and rested do you feel?
Good Morning	Did I catch you at a good time?	Has today been full of things that are interesting?
Good Evening	Is this a bad time?	How stressed do you feel right now?
Its getting late….	Do you have a minute?	Do you feel anxious about anything?
Afternoon	Ready for more questions?	How capable do you feel in finishing all your tasks?
Hi	Is this a good time?	How are you feeling in general?
Hello <user name>.	Should I continue?	How pressured do you feel right now?
Sorry to bother you again…	Can I take a minute of your time?	Have you felt anxious within the last hour?
Hope you're having a nice day.	Should I continue with questions?	Has anything stressful happened in the last hour?
Hey there.	Is this a good time to ask questions?	How are you feeling?
Just wondering…	Is this a bad time right now?	You know the drill -- feeling stressed?
Its me again	Do you have a moment?	
Here we go again	Can I steal a sec?	
Hey <user name>	Should I go on?	
Touch screen to begin	Got a sec?	
You know the drill	Is this a good time for you?	
Knock, Knock	Oh. Something interesting. Got a sec?	
Hi there	Oh. New place. This a good time?	
Whew, I have to remember to wake up sometimes.		

Answers

Answer 1 (negative)	**Answer 2**	**Answer 3**	**Answer 4**	**Answer 5(positive)**
Not at all :(	Could be much better	OK	Pretty good	Very refreshed and relaxed
Not at all :(	Not really	Nothing stands out	Yeah. I think so.	Definitely
Stressed out	Pretty stressed	So-so	Barely any	Not stressed that much at all
Very much so	Yeah. Some things are on my mind	Ok	Not much	Nope
I can't do it	Not sure if I can	Just Ok	Pretty capable	Sure. I can do it.
Much worse than usual	Not good - but not the worst	So-so	Pretty good	Great
Very pressured.	The pressure is definitely there	Not bad - not good	Not much	Not at all!
Yes!	Somewhat	Nothing stands out	Not really	Not at all
Definitely	Somewhat	Nothing bigtime	Not really	Nope

Much worse than usual	Pretty bad	In between	I'd say things look bright	Great day
Yes!	Its there - but not the worst	Same old - same old	Not really. Thanks	Nope!

Responses

Very stressed	**Stressed**	**Neutral**	**Low Stress**	**Very Low Stress**
I'm sorry to hear that. I hope you feel better soon.	Really sorry to hear.	Seems things are going pretty neutral.	Seems like you're feeling good. Good to hear.	Great to hear!
Sounds really bad. I'm sorry that you're feeling that way. :(	Wish it was better. Hope things start looking up.	Seems like things are going ok.	Glad to hear.	Awesome. Have a good day!
Wow. You sound pretty stressed out. Hope things start looking up.	Sorry to hear -- hope things calm down.	Doesn't sound too bad. Hope your day picks up.	Looks good. Happy to hear.	Sounds great!
Doesn't sound too good. I'm sorry to hear. :(	Sounds like you're pretty stressed. Sorry to hear.	Sounds like it's one of those so-so times.	Seems like things are going well. Nice. :)	These are the best! :)
	Sounds pretty bad. Hope things get better.		Sounds pretty good.	Happy to hear
			:)	Wonderful.
				Nice! :)

Thanks

Thanks so much for all your input. I hope I haven't been too frustrating.
Thanks for all your input. It really helps both of us learn more about you.
You've been great at giving me input. Really appreciate it, thanks.
Great input. Thanks!
Really useful stuff. Thanks!
Every bit of information helps. Keep it up!
Thanks. Don't forget that you can annotate things that are interesting to you.
Thanks. Hope you're having a nice day.
Thanks.
Have a good day.
Great, take care.
Great job. I'm collecting a lot of useful information.
Thanks. You've been great with annotations.
Thanks. Until next time.
I know it can be frustrating to answer all these questions, but every bit helps.

Appendix C: Source Code

Radial Plot

```
function [xval,yval] = radial(theta, rho, style, annotate, answer, varargin)
%   RADIAL  radial coordinate plot.
%   radial(THETA, RHO, ANNOTATE, STYLE) makes a radial plot using polar coordinates of
%   the angle THETA (time values in min from origin), in radians, versus the radius
%   RHO (heart rate value in bpm).
%   If annotate (hh:mm:ss) is given, it plots a annotation mark where one was made
%   during the study.  Style is either 'HR' or 'entropy' where HR is just a
%   heart rate plot and entropy uses a kalman spectral estimation with
%   entropy.

%   author:  kkliu@media.mit.edu
%   date: 4/2004

%figure;
if strcmp(style, 'HR') == 1
%%%  Run Radial plot for HR, otherwise create a radial plot for entropy

        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        %%%
        %%%  plot a circle with spokes and annotations
        %%%
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        %% set min, max radius and number of ticks
        rmin = 0;
        rmax = 180;
        rticks = 3;

        % define a circle
        th = 0:pi/50:2*pi;
        xunit = cos(th);
        yunit = sin(th);

        % draw radial circles
        c82 = cos(82*pi/180);
        s82 = sin(82*pi/180);
        rinc = (rmax-rmin)/rticks;
        i=rinc;
        for i=(rmin+rinc):rinc:rmax
            hhh = plot(xunit*i,yunit*i,':k'); axis(rmax*[-1.5 1.5 -1.25 1.25]); hold on;
            text((i+rinc/20)*c82,(i+rinc/20)*s82, sprintf('%i bpm', i));
        end
        set(hhh,'linestyle','-') % Make outer circle solid

        % plot spokes
        th = (1:4)*2*pi/8;
        cst = cos(th); snt = sin(th);
        cs = [-cst; cst];
        sn = [-snt; snt];
        plot(rmax*cs,rmax*sn,':k');hold on;

        % annotate spokes with time labels
        rt = 1.2*rmax;

        text(rt*cst(1),rt*snt(1),'3am');
        text(rt*cst(2),rt*snt(2),'Midnight');
        text(rt*cst(3),rt*snt(3),'9pm');
        text(rt*cst(4),rt*snt(4),'6pm');
        text(-rt*cst(1),-rt*snt(1),'3pm');
        text(-rt*cst(2),-rt*snt(2),'Noon');
        text(-rt*cst(3),-rt*snt(3),'9am');
        text(-rt*cst(4),-rt*snt(4),'6am');
        %text(-rt*cst(5),-rt*snt(5),'8am');
        %text(-rt*cst(6),-rt*snt(6),'6am');

        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        %%%
        %%%  plot HR and time vals on radial plot
        %%%
```

```
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        %% plot only red values greater than 95 (this loop is done twice so that
        %% the color overlaps well
        for i=1:length(rho)
            th = (360-theta(i))*2*pi/1440;
            cst = cos(th); snt = sin(th);
            cs = [zeros(1,length(cst)); cst];
            sn = [zeros(1,length(cst)); snt];

            %% set yellow color for HR > 95
            if (rho(i)>95)
                 %% plot yellow for anything over 95
                 plot(rho(i)*cs(:,1),rho(i)*sn(:,1),'-r');hold on;
            end
        end

        for i=1:length(rho)
           th = (360-theta(i))*2*pi/1440;
           cst = cos(th); snt = sin(th);
           cs = [zeros(1,length(cst)); cst];
           sn = [zeros(1,length(cst)); snt];

           if (rho(i)>95)
                 %% plot HR val in blue until 95
                 plot(95*cs(:,1),95*sn(:,1),'-b');hold on;
          else
                 %% plot rest of HR values less than 95
                 plot(rho(i)*cs(:,1),rho(i)*sn(:,1),'-b');hold on;
          end
       end

        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        %%%
        %%%  plot annotations on radial plot
        %%%
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        for i=1:length(annotate)
            th(i) = (360-annotate(i))*2*pi/1440;
            cst = cos(th);
            snt = sin(th);
             xval(i) = 150*cst(:,i);
             yval(i) = 150*snt(:,i);
            plot(xval,yval,'*m');hold on;
         end
else

    %% plot radial for entropy

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %%%
    %%%  plot a circle with spokes and annotations
    %%%
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        %% set min, max radius and number of ticks
        rmax = -(min(rho)+40);  %% negative value so setting lowest negative value as the max
        rmin = 0;
        rticks = 3;

        % define a circle
        th = 0:pi/50:2*pi;
        xunit = cos(th);
        yunit = sin(th);

        % draw radial circles
        c82 = cos(82*pi/180);
        s82 = sin(82*pi/180);
        rinc = (rmax-rmin)/rticks;
        i=rinc;
        for i=(rmin+rinc):rinc:rmax
            hhh = plot(xunit*i,yunit*i,':k'); axis(rmax*[-1.5 1.5 -1.25 1.25]); hold on;
            text((i+rinc/20)*c82,(i+rinc/20)*s82, sprintf('-%03i', i));
        end
        set(hhh,'linestyle','-') % Make outer circle solid

        % plot spokes
        th = (1:4)*2*pi/8;
        cst = cos(th); snt = sin(th);
        cs = [-cst; cst];
```

```
        sn = [-snt; snt];
        plot(rmax*cs,rmax*sn,':k');hold on;


        % annotate spokes with time labels
        rt = 1.2*rmax;

        text(rt*cst(1),rt*snt(1),'3am');
        text(rt*cst(2),rt*snt(2),'Midnight');
        text(rt*cst(3),rt*snt(3),'9pm');
        text(rt*cst(4),rt*snt(4),'6pm');
        text(-rt*cst(1),-rt*snt(1),'3pm');
        text(-rt*cst(2),-rt*snt(2),'Noon');
        text(-rt*cst(3),-rt*snt(3),'9am');
        text(-rt*cst(4),-rt*snt(4),'6am');
        %text(-rt*cst(5),-rt*snt(5),'8am');
        %text(-rt*cst(6),-rt*snt(6),'6am');

        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        %%%
        %%%  plot entropy and time vals on radial plot
        %%%
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        for i=1:length(rho)
            th = (360-theta(i))*2*pi/1440;
            cst = cos(th); snt = sin(th);
            cs = [zeros(1,length(cst)); cst];
            sn = [zeros(1,length(cst)); snt];
            plot(-(rho(i))*cs(:,1),-(rho(i))*sn(:,1),'-b');hold on;
        end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%
%%%  plot annotations on radial plot
%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        for i=1:length(annotate)
             th(i) = (360-annotate(i))*2*pi/1440;
            cst = cos(th);
             snt = sin(th);
            xval(i) = (rmax-40)*cst(:,i);
             yval(i) = (rmax-40)*snt(:,i);
            plot(xval,yval,'*m');hold on;
        end
end
```

Heart Rate Thresholding Algorithm

```
function [w] = HRthresh(z)
%% This function returns a thresholded HR in bpm where 50 < HR < 120


n=1;
for i=1:length(z)
    n = find(z <= 50);
    if (~isempty(n))
        if (n(1) == 1)
            z(1) = 70;
        else
            z(n)=z(n-1);
            w=z;
        end
    end
end

%% throw away any value greater than 120
m=1;
while (sum(m) ~= 0)
%if 1
    % m=find(z*60 >= 120);
    m = find(z >=120);
    %% check to make sure the first one isn't m
    if (~isempty(m))
        if (m(1) == 1)
            z(1) = 70;
        else
            z(m)=z(m-1);
            w=z;
        end
    end
end
```