Mind the Body! Designing a Mobile Stress Management Application Encouraging Personal Reflection

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ABSTRACT
We have designed a stress management biofeedback mobile service for everyday use, aiding users to reflect on both positive and negative patterns in their behavior. To do so, we embarked on a complex multidisciplinary design journey, learning that: detrimental stress results from complex processes related to e.g. the subjective experience of being able to cope (or not) and can therefore not be measured and diagnosed solely as a bodily state. We learnt that it is difficult, sometimes impossible, to make a robust analysis of stress symptoms based on biosensors worn outside the laboratory environment they were designed for. We learnt that rather than trying to diagnose stress, it is better to mirror short-term stress reactions back to them, inviting their own interpretations and reflections. Finally, we identified several experiential qualities that such an interface should entail: ambiguity and openness to interpretation, interactive history of prior states, fluency and aliveness.

Keywords
Biosensors, wearability, interactional empowerment, stress

INTRODUCTION
Recent advances in biosensor technology, particularly its miniaturization and improved wearability, have generated a wave of applications designed to improve performance in athletes or to monitor people in everyday life [9, 23]. The aim in these systems is primarily to produce high-quality data to be remotely analyzed by healthcare professionals or users with expert knowledge. We became interested in whether we could design systems that instead would empower end-users to draw their own conclusions about their health—in particular related to stress. While it is acknowledged that long-term stress can lead to chronic illnesses [16, 27, 28], such as cardiovascular problems, it is difficult to know when the limit is reached and what to do about it. In the midst of a busy lifestyle, it is not easy to get a grip on what is stressful, what really makes us feel good, and which lifestyle choices or behaviors we should alter. It might be that we do not allow ourselves enough sleep, that we use alcohol to relax, or that we remain in a workplace that we should have left a long time ago. Some of these behaviors we might not even want to recognize or alter [6]. This opens a challenging design space for systems to be used by non-expert users, to help them better manage their lifestyles before they feel the need for medical attention. A few stress management systems already exist that, through the use of wearable biosensors, either display the raw bodily data to the user or take an expert role by interpreting the data into a level of stress.

In the explorations that we describe herein, we identify three issues that to some extent question the diagnose-and-warn approach: (1) the inadequacy of diagnosing stress as a pure bodily condition, removed from our subjective experiences of being able to cope, enforcing a reductionist perspective on detrimental stress and how to deal with it; (2) the difficulties of making any kind of robust diagnosis based on biosensors worn as part of our everyday life, outside of a controlled laboratory environment; and (3) the need to seriously consider sensor wearability when choosing their placement, sometimes having to compromise on the quality of sensed data.

To address these three issues we embarked on a long user-centered design journey, ending up with a system we name Affective Health. The interaction design of Affective Health is based on an interactive affective stance—borrowed from the affective interaction field—empowering users to link the complexities of everyday life, subjective experiences, and body data into a non-reductionist whole [2, 15]. The system uses skin conductance, heart rate and accelerometer sensors that transmit data to the users’ mobile phones in real-time. The user interface, on the
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A stress response is characterized by a combined activating all available resources to confront it or adapt to it. A stress response is characterized by a combined physiological and psychological state of arousal with a direct relationship to increased responsiveness and alertness leading to increase of heart rate, blood pressure, and perspiration. The problem arises when the arousal reaction is not shut down, releasing stress hormones such as cortisol, for a sustained period maintaining the blood concentration of these hormones on a high level [7,9, 27]. If this reaction is not shut down, i.e. if we do not relax, it can hinder the capacity of the body to heal in the long term, stepwise progressing towards illness.

The first models that attempt to explain stress date back to 1936 [28]. These consider only physiological aspects of the physical adaptation to threats. Observed bodily reactions included increased heart rate, dilation of pupils, and perspiration. Later models of stress [16, 27] also consider factors such as the individual perception of the stress experience. Our personality, perception of the situation, and our ability to cope with negative life experiences can be either attenuating or aggravating factors affecting long-term health damage [ibid]. As much as the body of research on stress has grown in the last few decades, it is still unclear exactly how stress affects our health and how the different factors interact.

To manage stress, clinical therapists often use tools that stimulate introspective analysis. One way to achieve this is through journaling. Keeping a journal or diary keeps people in touch with themselves by providing an anchor to everyday life, giving some control and closure over past events. A diary can help to identify hidden sources of stress, reason about and ultimately to cope with them. Another important aspect of stress management is body awareness or mindfulness [6, 18, 22]. Yoga and meditation are examples of activities with such goals that are usually recommended as adjunctive therapy to reduce stress.

Biofeedback can be used successfully as complementary therapy [10]. Data obtained from biosensors in controlled sessions with a therapist can give patients some insight in inner bodily processes, thus leading to increased control of bodily reactions. The data may also assist the therapist to gain an enhanced understanding of the patient’s personal reactions to stress (a stress profile).

**Stress management approaches using technology**

Several attempts to build devices or applications specifically designed to help people deal with stress without professional help have been proposed. A number of systems aim to promote relaxation, some of them providing biofeedback as well. StressEraser¹ and emWave² are commercial products with similar designs. Both come in the shape of a small portable box that sense heart beat patterns to assist users to relax. These systems interpret the natural occurring variations of the time intervals between heart beats, read from an infrared finger sensor, which is displayed in a simple graph. The systems rest on pure biofeedback by encouraging users to relax and immediately observe changes in their heart beat patterns. Both systems include information about breathing relaxation techniques and other kinds of stress management.

Other commercial systems take an expert role by interpreting the bodily data and mapping it to stress levels. Cocoro Meter [39], for example, diagnoses stress based on saliva samples. By measuring the quantity of enzymes, such as amylase, produced during stress reactions, those tools are able to approximate how much stress the users have been exposed to recently.

The above systems were designed for sporadic interaction, but systems designed for everyday use are more relevant to our design process. There is a fair a number of lifestyle assistants³ which require regular input of, for example, exercise logs, calorie intake, and number of work hours. These generic systems work as wellness diaries, allowing users to keep track of progress in different areas. By assisting users to reflect on their lifestyles they can also

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1 http://stresseraser.com/
2 http://www.heartmathstore.com/
3 http://www.personalinformatics.org/
help in managing stress. But, to our knowledge, there are no commercial systems that combine those characteristics with automatic collection of bodily data.

There is an important body of research that focus on continuous, biosensor-based, stress detection for everyday settings [e.g. 13, 14, 24, 25]. The common goal appears to be mapping bodily data to negative mental states such as anger or anxiety. These systems stem from recent research and development of surveillance systems for monitoring elder and chronic patients in home settings [9, 30], sometimes taking on an expert role to replace specialists in trivial situations or for detecting emergencies, for example, a medication dispenser that reminds the patient to take the pills while collecting bodily data before and after the medication [1]. While the approach can be positive in certain settings, when it comes to stress management, especially if we consider traditional stress management techniques employed by professionals where mindfulness and taking control over one’s life is central, we realize that these systems are employing a quite different model—instead of dealing with the causes of stress, the systems simply diagnose and monitor the symptoms.

II. SENSING BODILY REACTIONS TO STRESS

Based on a medical exploration of stress, we set out to find biosensors that could pick up on measurements relevant to stress symptoms. For this we have conducted a literature review. The measurements that those sensors pick up on must also mirror users’ bodies in ways that make sense to them, with no need for expert interpretation. These conceptualizations should also relate to behaviors and processes in our daily life, which users with no medical knowledge can easily understand and relate to. Guided by our previous experience when designing a digital diary called Affective Diary [31] and meetings with clinical stress specialists, we initially focused on adaptability and arousal.

- **Adaptability**: the concept of adaptability comes mainly from the concept of coping, i.e. the process of shutting off, both physically and emotionally, a stress response. Since an excess of stress disrupts the normal internal processes of the body, not coping properly with stressors is the main reason why stress leads to illness [27].

- **Arousal**: the basic manifestation of short-term stress—a combined physiological and psychological state with a direct relationship to increased responsiveness and alertness leading to increase of heart rate, blood pressure, and perspiration.

**Focus on wearability and comfort**

But is it at all possible to collect bodily data that relate to arousal and adaptability in a non-intrusive way in everyday life situations? When designing a wearable device intended to be used by healthy people who fear that they risk stress-related problems or simply desire help to live a healthier life, considering the issues of comfort and unobtrusiveness is essential. People with already identified cardiac problems might accept to carry a heavy heart monitor but a lifestyle application must be comfortable. It must also camouflage with everyday accessories or clothing in order to avoid awkwardness or social stigma [23, 36].

In everyday settings users are likely to be bothered by sensor placement and calibration hassle. Moreover, users are seldom qualified to identify when the signal is correctly acquired, which, in combination with unpredictable everyday life settings, may result in noisy and useless sensor data. We decided to base our choice of sensors on the following list of requirements.

The sensors should:

1. measure bodily features\(^5\) that could capture arousal and adaptability;
2. be comfortably wearable, mobile, and unobtrusive;
3. provide reliable and consistent output with minimal personal variation; and
4. be robust and durable, as well as requiring minimal or no maintenance.

We also had to limit requirements on complex signal processing due to limitations of battery, processor, and memory usage in order to promote wearability.

**Can we sense adaptability?**

Ongoing medical research is still trying to uncover the processes by which the accumulated damage from stress gives rise to illness. It has been shown that degeneration of the body due to exposure to stress can be diagnosed from at least ten physiological markers [27]. Most of these cannot be measured non-invasively\(^6\) as the signals used were mainly related to the concentration of different hormones in the blood related to internal body regulation. Though there are systems that can measure stress markers in the saliva, see above, such measurement method is not practical for lifestyle applications in everyday settings.

Literature suggests that heart rate variability (HRV), which is the inter-beat variation of the heart, decreases with both physiological arousal and long term wear and tear of the body [4, 8, 25, 30]. Still, we discarded the measurement of HRV for two reasons. First, a measurement fault of missing one heart beat would give an extremely large variation, thus being very error prone [5, 8]. Second, the physiological research community has failed to reach consensus regarding the interpretation of HRV data [5, 19, 30],

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\(^4\) Personal communications with MDs Yrsa Sverrisdottir, Ingibjörg Jonsdottir and Gunnar Ahlborg from Institute of Stress Medicine, Gothenburg

\(^5\) By *features* we mean measurable characteristics of the bodily data, e.g. heart rate and the variation of time between heartbeats.

\(^6\) A technique is *non-invasive* when no break in the skin is created.
preventing widespread clinical application. Therefore, the study of HRV has to mature before it can be used to provide unassisted biofeedback to non-expert users.

Blood pressure is, as well, a promising marker of detrimental stress [27]. Unfortunately, most measurement methods do not qualify for permanent use in everyday life, requiring inflatable cuffs or bands that exert constant pressure on the skin. The less invasive techniques require a number of sensors around the fingers obstructing the free use of hands [21].

Delayed cardiovascular recovery, i.e. the time required for the heart rate to return to normal after being increased due to stress, seems to be associated with the risk for stress injuries [26]. A delayed recovery is related to the concept of physiological coping since the stress response will not be shut down until we stop worrying. However, there is a large individual variation in delayed cardiovascular recovery, both in short term responses and in long-term stress recovery, like the one happening right after a stressful day at work. Measuring adaptability based on cardiovascular recovery was thus discarded due to inconsistency and large individual variation.

This led us to conclude that, at present, there is no single feature or combination of features that can reliably characterize the damage of long-term stress and unhealthy lifestyle. All reviewed methods were either invasive or required clinical medical interpretation to make sense. For this reason, it made little sense to try to do a best-effort representation of adaptability.

**Methods for sensing arousal**

As the arousal resulting from a stressful event is a reaction occurring in the whole body, there is a variety of measurable body signals reflecting physiological changes [7, 9, 28]: release of hormones, brain wave activity, dilation of the pupils, muscle contraction (especially in facial muscles), higher breathing rate, changes in skin temperature, increased cardiovascular activity (e.g. increased heart rate), and electrodermal activity (i.e. changes in the skin conductance of electricity due to emotionally related perspiration).

Out of these bodily reactions hormones are hard to measure non-invasively. Brain waves, pupil diameter, and muscle contraction require bulky sensing apparatus, which is hard to wear in everyday life. Sensing breathing rate requires measuring the contractions of a band firmly pressed around the chest, which can be uncomfortable for the user. Skin temperature is a good indicator of arousal [7] that can be measured with simple sensors placed almost anywhere on the body. However, skin temperature is very sensitive to the normal internal body regulations and environmental temperature. Skin temperature could therefore not be used without extensive modeling, including contextual modeling, which is difficult in real-life settings (in addition to memory- and processing consuming).

Different measurements of the heart activity are more promising [5, 8, 25]. Heart rate, or pulse, is both an easily measured feature, strongly related to arousal and stress, and easy to conceptualize for end-users. Heart rate can be measured by detecting peaks in the signal collected from sensors on the wrist or finger by using blood volume pulse sensors [5]. However, a better signal quality is usually obtained with the more traditional electrocardiogram (ECG) sensors [ibid]. ECG electrodes can be placed on many different places of the body without compromising signal quality, and there are well-known algorithms for extracting heart rate from ECG in real-life settings [33].

Finally, there is electrodermal activity. When a constant voltage is applied at two points of the skin, the result is a current flow that changes over time due to variations in skin conductance. The rapid occurring fluctuations, called galvanic skin responses (GSR), are caused by dilatation and perspiration in special sweat glands called eccrine glands, which are related to arousal [3]. Though these glands exist throughout the body, they are more concentrated on the forehead, palms and soles of the feet. At least around the palms of the hands, we envision that we could comfortably place skin conductance sensors. Besides GSR, electrodermal activity has a tonic component that changes slowly over time. This component, usually called skin conductance level (SCL), is related to the overall arousal level as well as other factors of internal body regulation [ibid]. When mapping skin conductance to arousal in real-life settings, it can be confusing for the user if one maps it only to GSR peaks, since these can occur naturally without any perceived external stimuli [ibid] as well as with breathing, digestion, etc. Similarly, by only looking at the SCL, one might miss important real-time information. Thus, a working real-time algorithm for usage in everyday-life would have to combine both these skin conductance features, as well as to cancel noise from movement [38].

A side from the long term and short term distinction, arousal can also be positive or negative in character. This valence dimension can be inferred by combining several sources of bodily, contextual information [14, 20]. Still, these results were created within a controlled setting during limited time, when the range of activities of the subjects was predictable (such as driving [14]). Instead of aiming to measure the valence of arousal, one option is to provide contextual information to the user along with arousal, allowing the user to make sense of the data herself. We can do this through the use of a movement sensor such as an accelerometer, which will assist in making the distinction between periods of arousal due to physical exercise and periods of arousal during rest.

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[7] Galvanic skin response can also be found in literature under the names of electrodermal response (EDR), psychogalvanic reflex (PGR) or skin conductance response (SCR)
Testing and choosing sensors
Our conclusions about sensors were driven not only by a literature review, but also by practical hands-on experience with different commercially available sensors (Polar\(^8\), BodyMedia\(^9\), and Exmovere\(^{10}\)). During the initial phase of the project, six members of the design team were equipped with heart activity, skin conductance, skin temperature, accelerometer, and pedometer sensors. The sensors were placed on their bodies according to the manufacturer recommendations, and worn during daily activities. In a workshop we correlated our subjective experience of the activities with the raw bodily data. We found that most often arousal could be linked to skin conductance and heart rate, but only if we linked it to movement. When moving a lot, perspiration and heart rate increase. Thus, skin conductance and heart measurements mapping to emotional arousal have to be seen relative to the baseline created by movement. Overall, we found that the measurements could not be seen as fixed numbers on a scale, but relative to the time of day, the activity at hand, the prior activity, and individual differences. We also found that the mathematical curves and numbers the system provided were hard to interpret, and thus difficult relating to our subjective experiences.

The sensor configuration we used\(^{11}\) was based on a Bluetooth-enabled device transmitting data in real-time to a mobile phone. The device was connected to a triaxial accelerometer, skin conductance sensor, and three-lead ECG sensors. These sensors, although designed to be wearable, were still prone to noise, interference, and poor contact with the skin in real-life settings. We therefore had to create encapsulations of the sensors in clothes and wristbands to increase wearability (see Figure 1). Our choice of platform for the implementation of the system was a modern mobile phone, or smart phone, since it possesses the interaction capabilities needed for the design of the system. A simple LED display would not allow for the rich interface we were aiming for.

The placement of sensors on the body is crucial since they only work when placed correctly, and since the chosen sensor placement influences the type and quality of the data. In addition, we were guided by recent literature on wearable and ubiquitous computing that focuses on minimizing the impact of biosensors on the body, while considering aesthetics and fashion \([23, 35, 36]\). The three sensors of our choice (skin conductance, ECG, and accelerometer) are relatively flexible and allow us to experiment with different configurations. Figure 1, on the left side, we illustrate a placement of sensors for integration with sports clothing or underwear. The skin conductance electrodes and the accelerometer are placed on the palm of the hand and the ECG leads are located around the chest. The right picture shows a configuration where all the sensors are placed on the wrists—the accelerometer, skin conductance and two of the ECG leads are on the left wrist and one ECG lead is on the right wrist. This configuration allows for easy connection and removal of sensors and illustrates how these can be integrated with bracelets or a wrist watch.

Figure 1. Two different sensor placements on our users
Because the placement of the skin conductance sensors on the wrist is not a standard placement, we conducted a validation study. The study was conducted in a controlled setting to investigate how the wrist placement affects signal quality. Measurements from both a standard finger placement and the wrist placement were collected simultaneously and preliminary results suggest that the two measures correlate significantly. While these results are promising, further analyses are being conducted to optimize the skin conductance algorithm to the wrist placement.

III. DESIGNING AND TESTING AFFECTIVE HEALTH
Intermingled with our explorations into medical and technical possibilities and limitations, we designed a range of different versions of our system and repeatedly tested them with users. Our tests were a mix of Lo-Fi testing \([37]\), fake scenarios in a Wizard of Oz-fashion \([11]\), testing the system on ourselves using an autobiographical design method \([29]\), and making end-users wear the system for a limited time. While testing the system on ourselves may seem unorthodox, it was sometimes the only way we could access relevant data on users’ experiences [ibid.]. In addition, for ethical reasons, we could not include people with stress illnesses, as we did not know whether the system would help them or induce even more stress.

As discussed above, the Affective Health system should provide: (1) a biofeedback loop allowing users to see their own bodily reactions in real time, and (2) assist users to find both the positive and the negative stressful patterns in their own behavior. Through our design explorations, we arrived at four experiential qualities that the interaction with the Affective Health system must exhibit in order to provide these two kinds of functionality: ambiguity and openness to interpretation, interactive history of prior states, fluency, and aliveness.

From Diagnosis to Reflection
Our early designs were based on the idea of showing users both arousal in the short term and adaptability in the long

\(^8\) http://www.polarusa.com/
\(^9\) http://www.bodymedia.com/
\(^10\) http://www.exmovere.com/
term. Our aim was also to move away from the standard mathematical interface designs used in most commercial systems, while still making the raw data available for interested users.

One of our early interfaces shows adaptability as the shape of a circle, almost like a fetal skin (see the white circle in Figure 2). If the user is healthy, the circle will be large and smooth, similar to the HRV with healthy, irregular heartbeat intervals. If the heart is beating too regularly, not adjusting to different situations, adaptability becomes low and the circle then becomes smaller and jagged in shape.

![Figure 2. Representing long-term adaptability and arousal](image)

The dots inside the circle will appear one after another, second apart, representing real-time information. If they are spread it means that the heart is beating irregularly, if they are gathered in the middle, the heart is beating regularly (as it should if the person is, e.g., exercising, but not if she is relaxing). Thus, by relaxing, the dots should be spreading, eventually increasing the white circle.

The color of the dots would be mapped to skin conductance—the more red and bright, the higher arousal, following a color scale all the way down to dark blue representing low arousal.

But, as discussed above, the existing sensors for measuring HRV in everyday life are not yet robust enough—a problem we ran into when testing different sensor solutions. Given that we could not measure the long-term effects of stress in a reliable way as part of everyday life, we had to look for alternative ways for users to notice and link short-term stress (arousal) periods to negative, long-term stressful experiences. The design stance we adopted, an affective interactional stance, was borrowed from the affective field [2, 15] as stress and affect are intimately connected.

The interactional perspective was originally defined by Boehner et al. [2] as a set of guidelines for design that view emotion as constructed in interaction, where the system supports people in understanding and experiencing emotion instead of inferring and representing it as discrete units of information. A system designed from this perspective will mirror users’ emotion in a rich form, allowing users to make their own interpretation, and possibly to change their behavior. As discussed above, reflecting on and learning how to modify one’s behavior or alter one’s subjective attitude to stressful events (finding coping strategies) are promising strategies for dealing with stress. We decided to design an interface that would mirror short-term stress, as measured by heart rate and skin conductance, allowing users to relate these events to their inner experiences.

Heart rate and skin conductance may increase from both negative and positive stress, and the sensors we use could not determine which. This means that the responsibility for interpreting an increase as negative or positive rests with the user. But as shown by the Affective Diary system, most users are fully capable to do so [31]. The point of the Affective Diary was not to make people reflect on and change their behavior, but to provide a rich material based on bio-sensors and mobile materials (such as photos and test messages) that they could organize into a “scrapbook”, describing their everyday life. In a user study the authors report that not only did users arrange artful descriptions of their everyday life, they also detected patterns in their bodily reactions that they wanted to change [ibid]. It was also reported that users were able to identify with the body memorabilia, and together with the mobile data, the system enabled them to remember and reflect on their past. Two of the subjects went even further and found patterns in their own bodily reactions that caused them to learn something about themselves and even attempt to alter their own behavior.

**Openness for Interpretation?**

But how could we represent arousal in the interface without telling the user whether it is positive or negative? We had to find interface modalities that could convey how arousal goes up and down, without necessarily conveying going up as always negative, and going down as always positive. At the same time, the representation must be consistent and provide clues for meaning-making. If the arousal goes up, this is a sign of more energy expenditure and activity.

Already when designing the Affective Diary system, as well as in the interface in Figure 2 above, we had been inspired by the idea of ambiguous interfaces and interpretative openness [12, 15]. We had chosen to work with color, shapes in different forms, and animations as means to achieve ambiguity. Colors do not have a given meaning, but in the western culture, red is often seen as containing the most energy while on the other end of the scale, with least amount of energy, we find blue colors. The use of color represents a layer of ambiguity, since a user can interpret the color blue as being e.g. bored, depressed, or calm depending on the circumstances. So, as we already have done in some of our early designs, we settled on using color to represent arousal, according to a color scheme by Stähl et al. [32]: a bright red indicates high arousal and dark blue denotes low arousal.

We map the skin conductance to the color scale by applying a real-time window to the skin conductance signal. This window combines the features of skin conductance peaks and long-term skin conductance level. A similar way of reasoning lead us to use different abstract, but still somewhat meaningful, shapes and animations (e.g. using a pulsating sphere to represent the beating of the heart extracted from the ECG signal).
On track? Testing a fake system
But would our users make sense of colors and shapes? And
what if providing real-time feedback would make our users
even more stressed? In a Wizard of Oz study, testing two
different visualizations on the mobile shown in Figure 3,
we got some useful design feedback [11].

The study was set up to vary between real-time or delayed
feedback (to possibly avoid stressing users), and to vary
between an interface that did not have any historical data
(leftmost interface in Figure 3), and an interface with
history portrayed as fading dots (rightmost interface).

Figure 3. Interfaces used in the Wizard-of-Oz study. The left
interface has only real-time feedback using color and flickering.
The right interface is the same as in Figure 1, but without the
circle portraying adaptability.

In short, we found that the design needs to include history:
without seeing previous states, we have no way of
determining whether the current state is heightened or more
aroused. Users also found it important that the interface
would feel alive: it needs to show users’ pulsating,
vibrating, body-relaxed or in full action. They therefore
preferred instances where they could see something
animated, reminding them of their heart or body in action.
It was also clear that it is important to show data in real-
time: otherwise the connection between what we do and
what the interface shows becomes disconnected and hard to
understand and identify with. Using color to portray arousal
worked well as an ambiguous modality, allowing both
negative and positive interpretation of arousal. We also
found that the interaction did not increase our participants
stress reactions, at least not during the two-hour test we
exposed them to.

Adding history, aliveness, fluency and correct level of
ambiguity
Based on the lessons learnt from the WoZ-study, using fake
non-working sensors, we designed several new interfaces12.
Two of these, see Figure 4, have been fully implemented
and tested with real sensors and Bluetooth transmission.

12 We have created around 15 different visualizations, which have
been designed and discussed in the project. Several are
portrayed elsewhere [37]. In parallel, we performed a range of
technical tests to check how fast the interaction using Bluetooth
as a means to connect sensors to the mobile could be, and how
many states we could store on the mobile phone.

History
In the Layers system, shown in top of Figure 4, the newest
to latest states in the history are layered from leftmost top
to rightmost bottom of the mobile interface. This concept
was inspired by nature and the picture of leaves falling to
the ground, building layers of historical data. Each layer
represents a summary of one minute of data. The topmost
layer is showing changes in real-time, and only when a
whole minute has passed will the system summarize the
minute (using the most prominent biosensor data averaged
from the whole minute) and let it fall down to the top
becoming yet another layer. Users can scroll back in time
by pushing layers upwards or downwards (using the finger
or the stylus pen of the mobile).

The Spiral system, shown in the bottom of Figure 4,
explores a circular perspective of time allowing users to
view their activities separated from standard units. One
element of cyclic time is the ecclesiastical (church) year
that is not a year of moving forward, it is rather an eternal
repetition of certain qualities of time: expectation, sorrow,
and sacred hope. In this interface the big centre sphere
shows data in real-time. This data is then translated into the
history that grows outwards in a spiral. With this interface,
it is easy to compare different states over time since they
are shown in parallel cycles: data from the previous
seconds, minutes, hours, or days are placed in the spiral
(with a maximum of three cycles in the spiral). By doing
so, users can start comparing and finding patterns in
different parts of their data. They can squeeze the data to
condense it (compress data), or stretch it to see more
detailed information.

Aliveness
Combining skin conductance and heart rate in the arousal
mapping could improve its accuracy [14]. However, heart
rate was represented separately for a number of reasons. Firstly, the heart is a widely used metaphor in western cultures, which makes pulse already so well known that does not require medical interpretation. Secondly, recent work in interactive body-centered art has demonstrated that it is possible to create an immersive experience by using the rhythm of the heart, pulsating in the interface. Finally, our stress medicine experts kept emphasizing “listen to your heart, it never lies”.

Thus, in order to enrich the feedback experience and increase the perception of aliveness, we portrayed pulse as a separate, organic, pulsating object in all representations. In the Layers interface, heart rate is portrayed by animated pulsations of the smooth, semitransparent circular shape. In the Spiral interface, the centre sphere is pulsating with the heartbeats, and past pulse is portrayed as the progression of semi-transparent bars that runs across the spiral.

Fluency
We have found that to have an active interface that is also pleasant to interact with, it is important that all changes in the interface happen in a fluent way, avoiding discrete states. This is a form of mimicry of live biological systems where changes can always be seen as process. As an example, the pulsation of interface elements to represent heart rate is never done abruptly; instead the transition is animated at a high speed. Similarly, the change from one color to another is always done by blending the two colors. As an example, real-time information in the Layers interface was visualized using a live blend of colors, an animated movement whirl, and a heart rate torus. Prior states, however, were summarized into static descriptions representing one minute of activity each. This created a disjoint experience between past and present.

The combination of the qualities of fluency and aliveness bring our system close to what Löwgren describes as pliability [17], i.e. the degree to which the user perceives the interaction to have a strong connection between action and outcome, coupled with a sense of interacting with a malleable digital material. It was suggested that this quality influences how much the users get involved and find the interaction aesthetically pleasing.

Not too ambiguous!
To address the need for interpretative openness, the designs are purposefully ambiguous. At the same time, we have to balance ambiguity and openness to interpretation with helping users to see the reality of what is happening.

In both the Layers and Spiral designs, the color represents arousal as measured by the skin conductance sensor. To help users to sort out when their arousal was mainly related to physical activity, we added accelerometer sensors picking up on their movement. That data was then mapped in different ways to the interface representation. In the Layers design, movement is portrayed as rotation of a star-shaped torus. In the Spiral interface movement determines the size of the centre sphere. Past movement can be read by looking at the size and progression of semi-transparent body that runs across the spiral.

By seeing movement portrayed together with arousal, users can discern which bodily reactions come from physical activity and which ones come from emotional arousal.

User experiences of the Layers and Spiral designs
We repeatedly tested these two designs on ourselves and by allowing others to use the system. A maximum battery life of six hours naturally constrained the length of individual sessions. We have yet to do a full, formal evaluation of our final system, especially because of the short battery lifespan and fragility of the sensors, but the evaluations so far provide several indications of a system that allows for reflections. Also, many of the small details added or corrected in the interfaces during this period of constant testing would be hard to obtain from a one-time formal user study.

First of all, both interfaces seem to be able to lead to increased body awareness. When using the Layers design, one test user noted that “...my life has been terribly hectic for the last week, [...]. I therefore had really high stress levels in my body. [...] I kept looking at the pulse-measurement to see if it was visible in the data [...] it made me very aware of the problem inside my body. I kept allowing myself to really feel how bad [my stress situation] is. I also experimented with taking a deep breath, trying to relax mentally, etc., but the pain did not go away.” This quote is interesting as it shows how increased body awareness may allow users to experience “how bad it really is”, and how quick fixes, “taking a deep breath”, are not enough. For this particular user, using the system was one of the experiences that led her to deeper reflections on her work situation and her choices in life.

The Layers interface was tested with five users outside our design team. The users liked the idea of history falling down into layers that they could scroll through. However, some of the users reported difficulties in finding a certain point in time in the history, both with respect to when it happened and the context in which it happened. It was suggested that the interface should provide contextual information (photos, sent and received text messages, and location information) making it easier to reflect on specific situations and events. But the main problem with the Layers design was that while it allowed users to easily compare color changes over time, the changes in heart rate, as portrayed by the pulsating sphere, was still hard to note. This led to the Spiral design that allows for easier comparisons of skin conductance (portraying arousal), heart rate, and movement measurements over time as it provides fluently blended states—both in color, shape and animation.

13 See, for example, George Khut work (http://georgekhut.com/) where he makes use of biosensors in interactive artwork. Visitors are invited to sit down and see their heartbeats or skin conductance measurements mirrored back to them in colorful, suggestive, organic shapes.
Another user tested the Spiral interface and found that it helped her to reflect on both positive and negative bodily reactions to meeting new people and being in a new environment. She focused on the real-time feedback since it appeared to convey a feeling of aliveness. However, as she had set the system to the second-by-second view, it initially provided a too narrow perspective of how she dealt with stress. When seeing that the entire interface was red, the fact that she dealt with stress so badly stressed her, thus making her even more stressed. After a while, she switched to a broader time span (from second to minutes) and realized that the data revealed both ups and downs and that her reactions over time were normal and closely related to her encounters with the new people in the office.

The Spiral design has been tested with three additional users. The overview provided by this design made it easier to find specific events, but more contextual information would still be helpful—in particular, we will in the future find ways of integrating contextual location data in the design. Representing time as a spiral was also confusing to some, as we are unused to view time in this form.

Lessons Learnt

We have provided a description of what was learnt from a designerly exploration into the mix of a medical understanding of stress, the material properties of bio-sensors, and interface design. Our explorations have shown that it is currently very challenging to diagnose stress from bio-sensors that can be worn comfortably and continuously in everyday situations. In the future, we will hopefully have biosensors that can sense stress-related symptoms, providing for correctness and robustness, but also for wearability and social acceptance. Until then, we can mirror short-term stress reactions in an interface that invites users’ own interpretations and reflections. By doing so, users can start finding patterns in their own reactions, linking short-term stress to their subjective experiences of long-term stress, coping with stress, finding resources that counterbalance the negative stress, and dealing with new people or a new workplace, thus becoming more body aware. A longer study is required to clearly see how the bio-feedback and reflections over time can help users to a more sustainable way of coping with negative stress, but the results presented so far are promising.

From our design explorations, we learnt about important experiential qualities needed in the design: an interactive history of prior bodily states, a sense of aliveness in the interface, fluent transitions between states for all variables measured, and most importantly, an ambiguous and open but still consistent design allowing for users’ own interpretation and reflections.

In terms of design methods, the decision to include our own experiences of using the system during the design process turned out to be a fruitful way of getting at hard to capture experiential qualities in the interaction. Those qualities are difficult to express for users being brought in for a brief test of a new system, outside their normal everyday life, and with an unclear feeling for what we aimed to design.

Finally, we want to emphasize that people may have many reasons to be stressed, or even want to live a life to its fullest and prefer a stressful life. We thus have to settle with providing people with tools that they can use to reflect on their everyday life and inform their own decisions about what they want to change (or not). We need to empower users to create their own stories about their physical and emotional well-being—preferably seeing the connection between the two in a holistic sense [18]. This is the design philosophy upon which the Affective Health variants are built.

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37. Anonymous, details omitted due to blind review.

