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DESIGNING AN INTEGRATED WEARABLE SYSTEM FOR BIOSENSING AND SELF-REPORTING OF STRESS

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Abstract

Stress is an important aspect of mental health which impacts on wellbeing. Wearable devices are increasingly used to help people deal with stress in daily life. However, most of the current applications focus on detecting and representing physiological data. In this paper we report on the design of an integrated wearable system composed of physiological sensors and a self-reporting interface. Through an iterative design process, we developed two prototypes and evaluated their technical performance in a laboratory condition. We elaborate on the issues we have encountered and addressed in the design iterations. We discuss how these lessons might contribute to the design of integrated sensing systems in real life. We end this paper by reviewing limitations of the study and directions for future work.

Keywords: smart wearables, stress management, design for mental health

Introduction

Dealing with stress on a daily basis is a significant aspect of mental health. Long-term stress affects people's quality of life and could cause cardiovascular diseases (Vale 2005). This issue is urgent especially for people with chronic mental illness, such as depression and posttraumatic stress disorder (PTSD). A variety of wearable technologies have been used to sense daily stress. Most of them rely on physiological signals, such as heart rate, electrodermal activity and respiration (Choi et al. 2012). Other applications include self-reports through smartphones in forms of labels or scales, and prediction algorithms through access to the person's digital life, such as personal schedules, emails, locations and daily activities (Garcia-Ceja et al. 2018). However, these methods are mostly applied in sporadic manners and not compatible with each other. There is a need to design wearables that integrate physiological sensors and subjective reports as sources of sensing stress.

In this paper we aim to design an integrated wearable system composed of physiological sensors and a self-reporting interface. Through two design iterations, we developed two prototypes and tested them in an experimental setting. Only male university students (n=12) were recruited for the experiment due to limitation of recruitment methods. We hope the lessons gained from this study will be beneficial for a more diverse group of people which we will include in future studies.

Design Iteration 1

Selection of physiological sensors

We selected physiological sensors based on literature study and individual tests. We chose three types of sensors targeting the biomarkers of heart rate variability (PPG heart pulse sensor), electrical conductance of the skin (Grove GSR sensor) and skin temperature (Thermistor – 3950 NTC). These biomarkers are most commonly used for measuring mental stress (Choi et al. 2012) and the relevant sensors are easily available on the market. We chose a data acquisition device (DAQ 6009) and a desktop software (LabVIEW) to collect and present the data on the computer screen.

Developing an intuitive self-reporting tool

We explored body movements and gestures that are related to stress expression. We chose the gesture of squeeze from those introverted gestures that are associated with expression of internal stress (Neff et al. 2010; Lefter et al. 2015). Accordingly, we developed a self-reporting tool (Figure 1) which is made of a standard force sensor (Grove – FSR402) and two pieces of foam. The sensor is connected to the computer through an Arduino board. The harder the user squeezes the tool, the higher level of stress is reported.

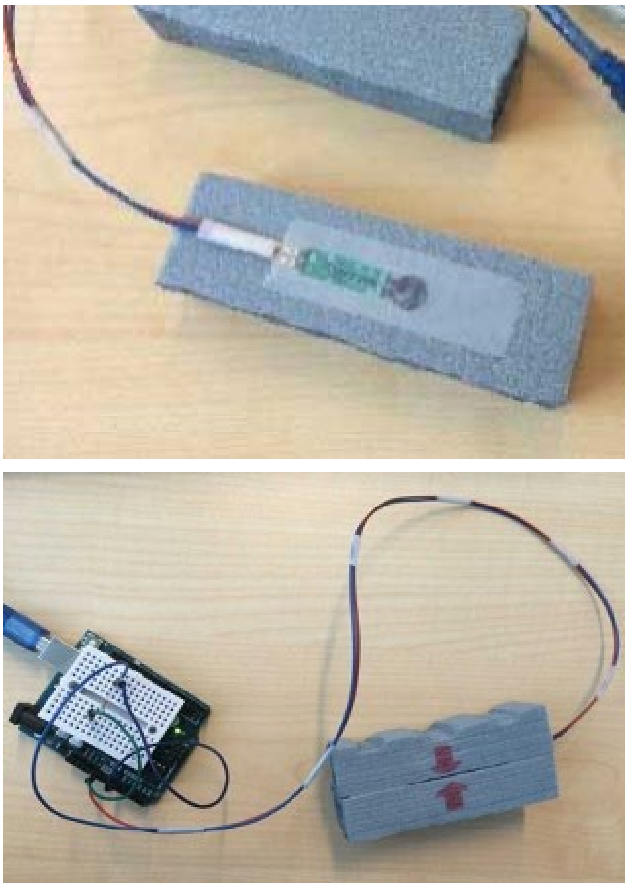

Figure 1: The self-reporting tool for Prototype 1

Placement of the sensors

We chose a vest made of a light and stretchy textile to attach the sensors closely to the skin. All the sensors were located on the left side of the chest to minimise the effects caused by body movements (as shown in Figure 2). Although these sensors have their recommended locations, their performance remains at similar levels according to our test. We covered the sensors and wires in between two layers and only the sensor heads that require contact with the skin were exposed.

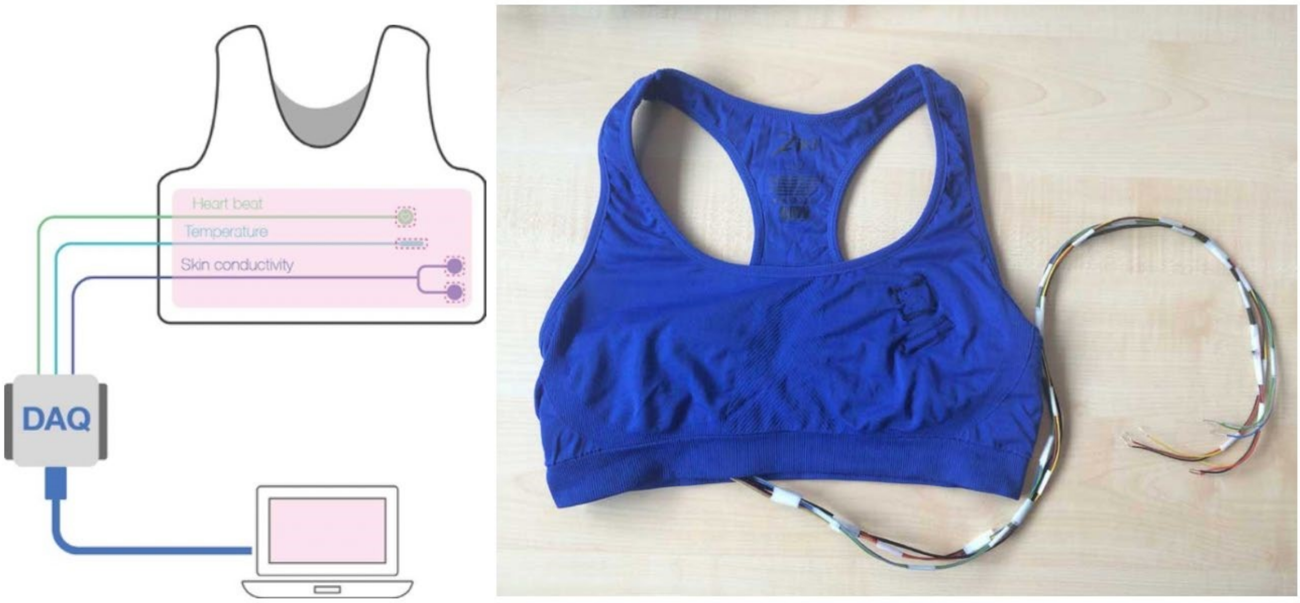

Figure 2: Connection of electronics and placement of sensors of Prototype 1

Evaluation

We introduced this prototype to 11 male university students (aged between 24 to 30) who wore it while being exposed to three simulated stressors. The participants were recruited through posters and personal networks of the experimenter (the third author). The experiment was conducted in a quiet room. The participant was asked to put on the prototype in advance and sit in front of a computer with a pair of headphones on. The experimenter sat beside him and observed the data generated on another computer connected to the prototype. The three stressors were adapted from those commonly used to induce stress in laboratory settings (Plarre et al. 2011; Choi et al. 2012):

Stressor 1: Fast reading The participant was asked to read a complicated article in 5 minutes. Meanwhile, an increasingly loud music was played through the headphones to form a slight disturbance. Mild stress reactions were expected.

Stressor 2: Mental arithmetic The participant was asked to continuously add up three-digit numbers without the help of any tool. The sound of a timer was played to increase the sense of time pressure. We assumed this would induce a middle level of stress.

Stressor 3: Sudden appearance of a scary image A clip of a video game was shown to the participant with a scary image placed at the end. Although the participant was briefed that there was an intense stimulus in this video clip, what and when it would show up were not revealed to them. The image was selected from a horror movie and intended to evoke immediate hypertension of the participant (Bosse et al. 2014). This stressor was discussed within the research team and reviewed by the ethical community of the university.

These three stressors were arranged in order with a 5-minute break in between each other. Before the experiment, we played a peaceful video to help the participant reach a baseline of stress. The same technique was used during each break to help him recover from the previous stressor. In the debriefing session, the participant was asked to rate the three stressors on a 5-point Likert scale, and share his experience of wearing and interacting with the prototype. An informed consent form was signed by the participant before the experiment. The proposal of the experiment was approved by the ethical community of the university before recruitment of the participants.

Outcomes

The raw data of the 11 participants show varied quality and is not suitable for correlation analysis. Instead, we took an individual approach to analyse the data of Participant 6 (P6), as shown in Figure 3. By doing so, we demonstrate the performance of Prototype 1 in correlation to the stressors and, with comparison to the observation of the experimenter, provide some insights on such changes of data. However, the results might be compromised by individual differences and require further research to develop into generalized knowledge. As can be seen in Figure 3, P6's heart rate data shows no clear correlation to the occurrence of the stressors. There were obvious downtrends in his skin conductivity since the beginning of Stressor 2 and by the end of Stressor 3 (where the scary image showed up). We see two sudden offsets before and after Stressor 3. This could be caused by body movements of the participant according to the experimenter's observation. The overall decrease of his skin conductivity indicates an accumulating effect of stress. This could be due to the fact that the participant was exposed to three types of stressors in a relatively short time. As for his skin temperature, the data shows no clear indication of immediate stress but a general uptrend with a short peak after Stressor 3. In contrast, his self-reported data captures the stressful moments more precisely. His self-reported data in real time and scores given to the stressors afterwards (via the Likert scale) show the same ranking order. We also notice a short delay after he was exposed to the scary image in Stressor 3, which corresponded to the observation that he froze for a few seconds before he squeezed the tool.

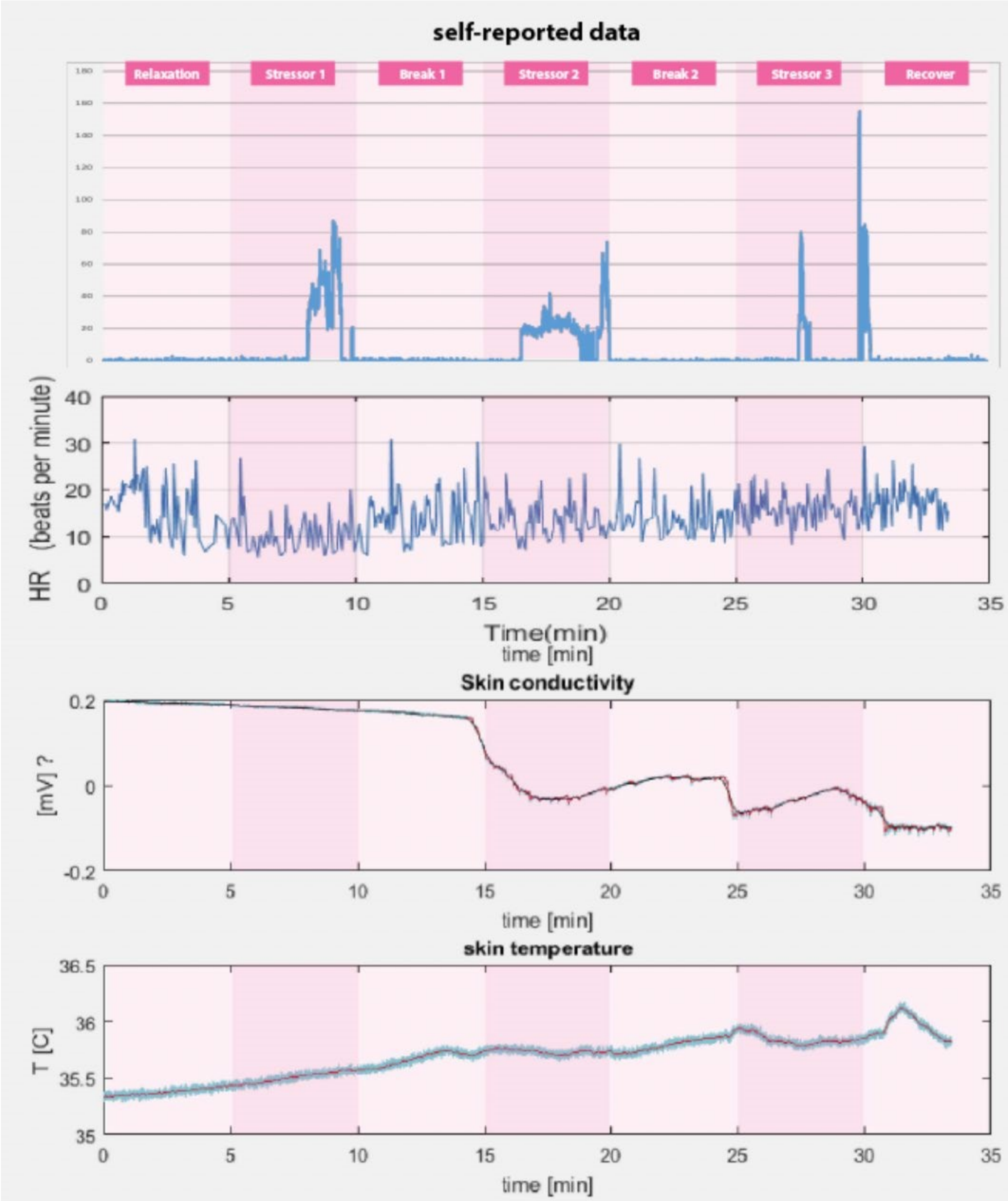

Figure 3: An overview of the bio-sensed and self-reported data of P6

From the debriefing interview, we had some feedback from participants (n=11) regarding wearability of the prototype and the self-reporting tool. Some participants (P1, P2 and P4) mentioned that Prototype 1 was too tight for their sizes. P3 and P5 wished for a more masculine design. As for the self-reporting tool, P1 mentioned that it was not well integrated with the vest. P2, P3 and P5 commented that using the tool could be distracting for the task at hand, and even made them more stressed. P3 and P9 mentioned it was difficult to report their stress when it happened to them unconsciously. P2 and P9 were uncertain about the force they should apply to the self-reporting tool and wished for immediate feedback of stress they just reported. We adopted some of the comments in the next design iteration.

Design Iteration 2

Style study and fashion design

At this step, we explored possible forms of the design. We came up with 5 concepts and made them into mock-ups using stretchy fabrics (Figure 4). We showed these mock-ups to the 11 participants and asked their opinions in terms of appeal and comfortability. Based on their feedback, we decided to combine the styles of Mock-up 2 and 5.

Figure 4: Conceptual mock-ups of Prototype 2

Update of electronics and the self-reporting interface

We updated the electronics and integrated the self-reporting interface with the garment. We added an accelerometer (MPU-6050) to detect movements of the main body. We changed the self-reporting tool into a ‘touch point’ (using the same pressure sensor) embedded on the left shoulder. The gesture of touching shoulders is considered as another natural way of expressing stress. We added a Bluetooth module (HC-05 Bluetooth) through which the garment could communicate signals to an alternative device (e.g. smartphones). We chose a small-sized Arduino board (Arduino Nano) and reprogrammed the code in a Python environment. A Battery (Lithium Ion) was used to support functioning of the prototype for at most 3 hours. We designed and 3D-printed a case using PLA material to accommodate the electronics and the battery. See Figure 5 for the design of the case and placement of the sensors on the garment.

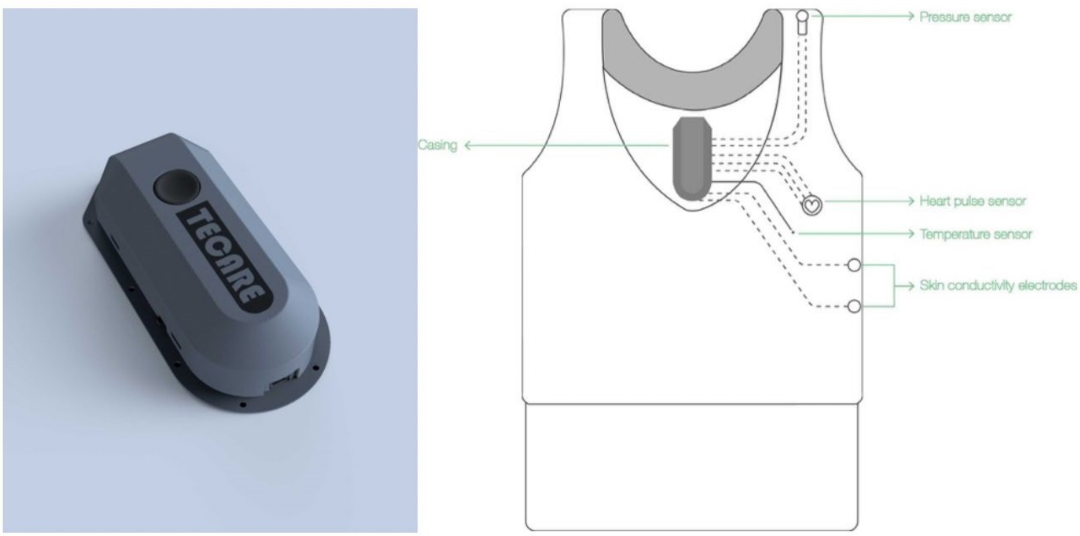

Figure 5: 3D modelling of the case and placement of electronics of Prototype 2

Integration of the electronics in the garment

We embedded the electronics in the garment accordingly. The prototype is made of two layers. The inner layer was adjusted from an elastic fitness shirt with all the sensors embedded (as shown in Figure 5). We used non-intrusive conductive threads on this layer to connect the sensors. The case was then added to the garment. Next to this, we added the outside layer to cover all the sensors, conductive threads and wires. We added elastic trips on the back and Velcro bands around the waist so that the user can adjust the size as needed. Figure 6 shows the final result of the development.

Figure 6: Finalization of Prototype 2

Evaluation 2

We conducted the evaluation of Prototype 2 following the same procedure as Design Iteration 1. Only one participant (P12) was recruited for a preliminary test. Instead of collecting and showing the raw data on the computer screen, the data was logged on the SD card and extracted for analysis afterwards.

Outcomes

Figure 9 shows the overview of P12's raw data. Similar to P6, it is difficult to indicate occurrence of the stressors based on his heart rate. Differently, his skin conductivity was unstable at the beginning and then showed an uptrend with slight drops after the second and third stressor. This indicates that the participant took some time to adapt to the experiment, and recovered from the stressors in a short time. His skin temperature shows a similar uptrend as P6, but no correlation to the stressors. The data collected by the accelerometer proves the disturbance of body movements to the physiological data. We recognize irregular fluctuations in heart rate and skin conductivity when there were sudden moves of the body. As for his self-reported data, he rated Stressor 2 and 3 as the most stressful ones via the self-reporting tool, while he gave the second stressor the lowest score on the Likert scale. This indicates the inconsistency between his real-time perception and recollection of stress. We should also note that his self-reported stress appeared as short pulses shortly after the stress events, rather than constant waves as shown by P6 (Figure 3). This indicates the difference of reporting behaviours between touching the shoulder and squeezing the hand.

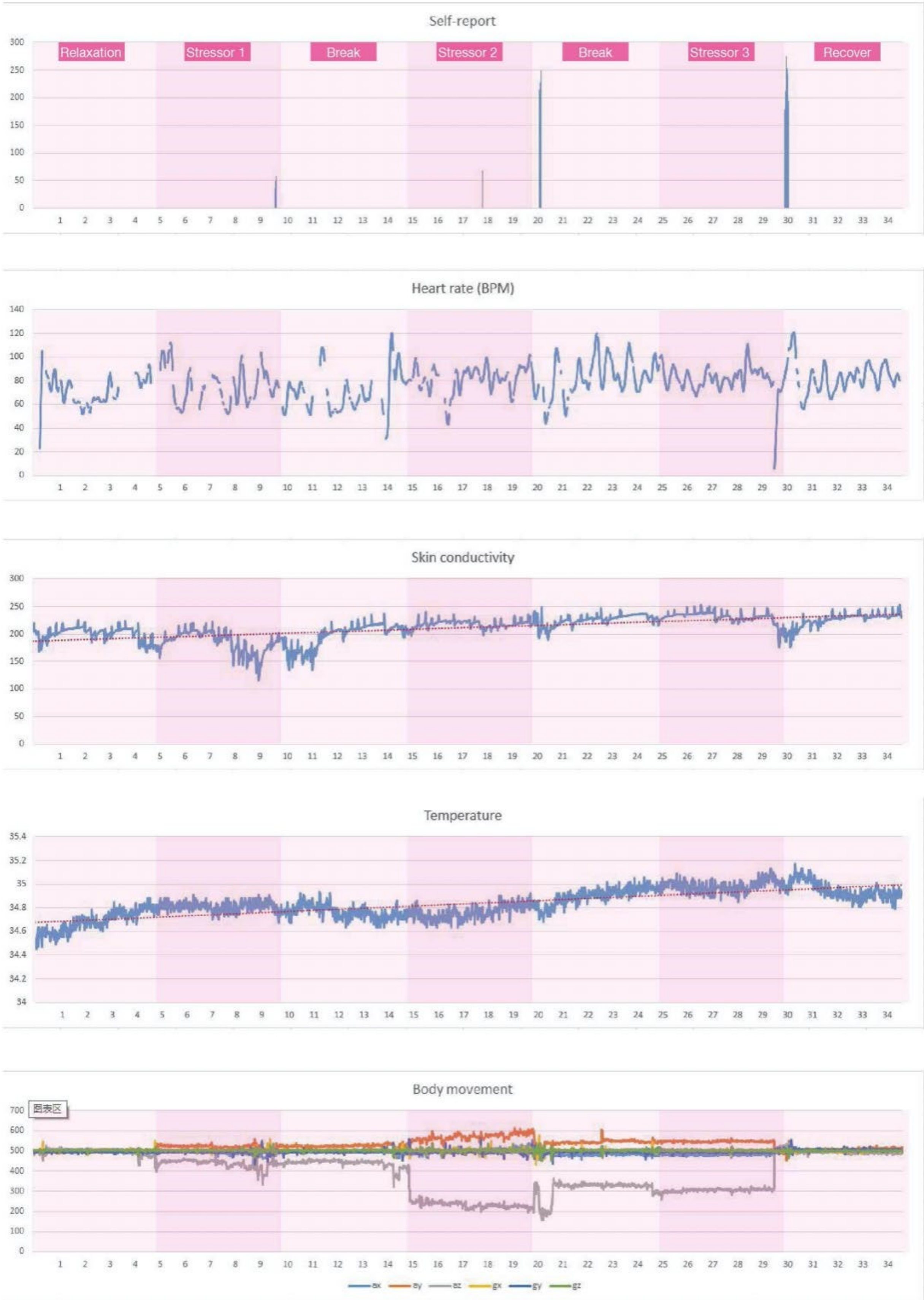

Figure 7: Bio-sensed and self-reported data of P12

In the debriefing interview, P12 appreciated this new way of reporting stress which reminded him of massaging the muscles. But he pointed out that 'it was difficult to find the right position of the pressing point'. He also commented that touching his shoulder required extra movement of his arm and thus difficult to do constantly, which was reflected in his self-reported data.

Discussion

Designing integrated systems for sensing stress

The bio-sensed and self-reported data show different characteristics in relation to stress which require specific analytic strategies and design considerations. The raw data of heart rate was easily disturbed and difficult to read directly. Skin conductivity appears to be sensitive to immediate stress, but the quality of data could be disturbed by body movements. The additional accelerometer proves to be useful to detect such disturbance. Some filtering algorithms can be used to address this issue by combining these sources of data. The skin temperature was relatively stable, but only showed general trends and vague relevance to stress.

In contrast, the self-reported data show potential to capture stress in the moment. Analysis of self-reported stress depends on the type of the sensor, location, and the behaviour required to use it. The self-reporting tool used in Prototype 1 shows advantage to report stress continuously, but it is inconvenient to use when the hand is occupied. A form of immediate feedback is needed for the users to be aware of their reported stress. Its modality also needs to be redesigned to be better accepted. A direction is to integrate it with existing wearable products, such as gloves and sleeves. The 'touch point' of Prototype 2 serves as an integrated interface on the garment. Compared with squeeze, the gesture of touching shoulders requires extra movement of the arm and might compromise the frequency of using it. Besides, we learn the importance of designing self-reporting interfaces to reduce overthinking of stress. Some participants (P2, P3, and P5) mentioned that checking stress could make them even more stressed. Inspired by P12, we can combine the self-reporting behaviours with relaxation exercises, for example, massaging shoulders. Finally, we acknowledge that it is difficult to design a one-fits-for-all self-reporting interface. We assume there should be an adaptive process before the conflict between mindfully reporting stress and paying extra attention to it decreases.

Limitations and future studies

There are some limitations of this study which inform us of directions for future studies. First, participants of this study are only male and aged between 24 and 30. Future work should include people of different gender, age and professions to promote our learnings from this study. Second, sensors applied in this study are limited due to their availability on the market, which are typically used for low-cost projects and not tailored for wearable products. More advanced sensors are needed to achieve better quality of data. Finally, we took an individual perspective to analyse the raw data generated by the prototypes. More thorough and quantitative methods are needed to investigate performance of the design with a bigger group of participants.

Conclusion

Dealing with stress on a daily basis is a complex issue that involves not only physiological changes, but also subjective feelings of the individual. In this paper we presented the process of designing integrated wearable systems that are capable of sensing both physiological and self-perceived stress. Results show that self-reporting interfaces are potential to capture immediate stress and complement an integrated understanding of stress. We reflected on the lessons of designing such integrated sensing systems and strategies to analyse the data collected. This paper serves as the first step towards designing smart wearables for daily stress, and is helpful for designers who are working on relevant topics.

Acknowledgements

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