WeaRelaxAble: A Wearable System to Enhance Stress Resistance using Various Kinds of Feedback Stimuli

Josephin Klamet
University of Magdeburg-Stendal,
Breitscheidstr. 2,
39114 Magdeburg, GER
josiklamet@googlemail.com

Denys J.C. Matthies
Fraunhofer IGD Rostock,
Joachim-Jungius-Str. 11,
18055 Rostock, GER
denys.matthies@igd-r.fraunhofer.de

Michael Minge
Technical University Berlin,
Dep. for Cognitive Psychology
and Cognitive Ergonomics,
Marchstr. 23, 10587 Berlin, GER
michael.minge@tu-berlin.de

ABSTRACT
This paper introduces a wearable feedback device that aims at relaxing the user in stressful situations. The system, which is called WeaRelaxAble, provides various feedback modalities, such as vibration, ambient light, acoustic stimuli and heat in order to reduce the user's stress level. The development of WeaRelaxAble is based on two studies: At first, all five kinds of feedback and appropriate body positions for stimulation were evaluated with 15 participants. Based on the findings of this initial study, we built a wearable Arduino prototype to prove the feasibility of our concept. The experience while using the system was tested with 26 test subjects under laboratory conditions. We conclude with a concept design of a wrist-worn device that provides acoustic and visual feedback. As tactile stimulation, a shirt would provide vibration at the positions of the shoulders as well as heat at the loins. Users can explicitly activate the system at any time and in any combination of feedback modalities.

Author Keywords
Assistive Technology; Stress Management; Wearable; Stress level; Feedback modalities; Vibration; Heat.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Stress in everyday life is a frequent symptom caused by different sources. Therefore, coping with physical and cognitive symptoms of stress in certain situations is an individual challenge that requires special techniques. In this paper, we propose a new approach - a wearable device that visualizes the user's stress level and enables an explicit control of different feedback modalities. We developed two prototypes and conducted two studies in order to gain insights into the users' perception and their personal preferences. Based on our results, we conclude with a design of a wearable system in form factor of a wristband and a shirt that potentially improves stress resistance.

Figure 1. WeaRelaxAble can be controlled from a wrist-worn arm-band. The figure displays a mocked-up rendering of our proposed system. The device is fastened to the arm and can thus capture body data, such as heart rate, skin conductance and heart rate variability. By means of the the blue icon buttons, several feedback modalities can be triggered. Feedback includes vibration at the shoulders, heat at the loins, as well as light and sound. The envisioned device incorporates a roll-up OLED display, which can be expanded from the side.

RELATED WORK
In this section, we briefly introduce prior work on thermal, vibrotactile, light and acoustic feedback used in Human-Computer Interaction (HCI).

Thermal
In general, the perception of temperature is an individual phenomenon as the expression of heat and cold thermal receptors is not similar across users. In physiological treatment, heat stimuli are used to ease muscles [11]. In contrast, cold stimuli can be beneficial to treat symptoms of exercise-induced muscle damage [4]. In HCI, thermal feedback can be applied in noisy and bumpy environments [17], however, it is still not broadly being considered.

Vibrotactile
Vibration is often an unintended feedback emitted from work tools [8] that can lead to disorders when someone is

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excessively exposed to heavy and prolonged vibrations. However, in low doses it is considered safe and represents an interesting feedback modality in HCI. Thus, it is most noticeable in terms of reaction time in comparison to heat, light, and poking [14], conveying quick notifications while minor-complex vibration patterns are also easily perceivable [1]. A wide variety of related studies shows that vibrational feedback can also be used for navigational purposes [9]. For instance , Meier et al. [9] investigated several body positions and found vibration to reduce stress, since the visual focus is not being demanded in stressful situations. In our opinion, using vibrotactile feedback to reduce stress needs to be further explored.

Light
Different light waves can affect the health of our bodies in a positive way, since bright light improves vitality and alleviates distress [12]. Moreover, it has been found that adjusting these individually to the user's rhythm yields the power for aiding the body. For example, orange light can be described as visually bright, as it is considered to be warm, activating and moving. As a matter of fact, dark orange light with a wavelength of 628 nm is generally perceived as comfortable. Also, pulsating light causes a quiet heartbeat and affects the brain wave activity and thus the state of consciousness. Furthermore, the brain is able to adjust itself to some external pulse frequencies [13]. In HCI, light has been used to create awareness while allowing to visualize binary information such as an ongoing energy consumption [16] or ambient information [10]. However, it remains unclear how we can incorporate an ambient light in wearables to relax or calm down a user.

Acoustic
Any kinds of sound, such as music or simple tunes, have a substantial impact [5] on our physical condition. Following literature, musical stimuli can have an effect on our subjective perception of pain, on our heart rate, blood pressure, breathing rate, oxygen consumption, metabolism, and brain activity [15]. It should also be noted that unpleasing noise may cause adverse mental state changes. Music instead can also be encouraging, inducing positivity and thus creating relaxation. It has been specifically proved that listening to music can create emotions such as joy and happiness right up to total intoxication [15]. In HCI, auditory interfaces are very common as they can be found everywhere (e.g., ringtone). In Virtual Reality (VR), audio effects also play an important role – such as to improve immersion [3]. For the purpose of relaxation, audio interfaces, such as a simple audio tape, have indeed been evaluated to be able to calm users down [5] and represent a potentially important approach that we will consider, too.

STUDY 1: DETERMINING FEEDBACK TYPE & POSITON
We developed a prototype providing five different feedback modalities: heat, cold, vibration, light and sound. In accordance with literature, we determined several anatomical positions that are quite sensitive and thus worth to be evaluated [2].

Research Questions
Q1: What kind of feedback is most appropriate for which body position?

Q2: Which types of feedback optimally calm users down?

Method
The evaluation was conducted in a laboratory environment with 15 participants (7 males, 8 females) with an age ranked between 25 and 45 years. Each user was asked to take a test session, which lasted for about 90 minutes.

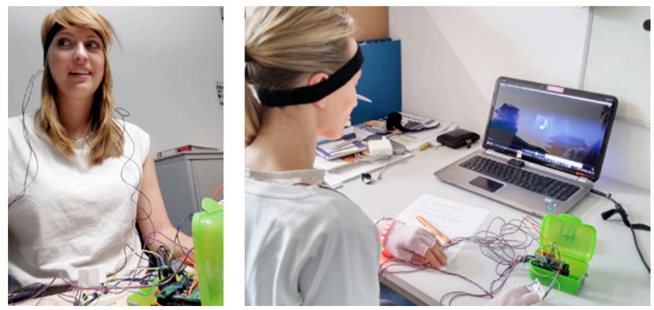

Figure 2. Apparatus – the first prototype consists of an Arduino Uno in a green box, while all actuators attached to the subject's body were wired to it.

Four feedback modules were attached to the participant's body while sound was being emitted by external speakers. We provided sound clips (bird noise, alpha waves, theta waves, heart beat) with around 75db. Heat and cold have been generated by a 15x15mm Peltier's element (TECI 1703). The light arm-band was strapped to the left wrist. The light was emitted by an ultra light LEDs (Adafruit Neo Pixel). The vibration was generated with a 3-6 V DC vibration motor (ROB-08449). The whole prototype was implemented by using an Arduino environment.

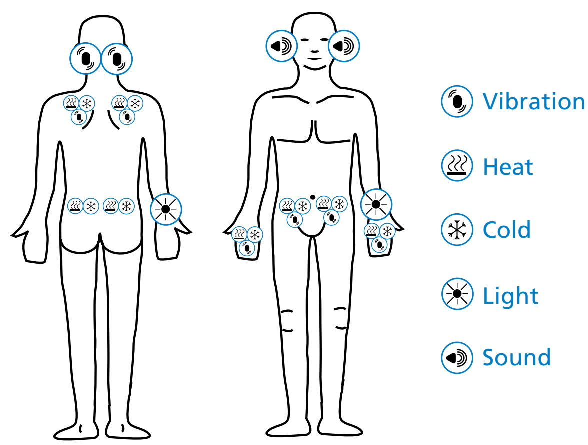

Figure 3. We tested 5 types of feedback at in literature popular body positions that yield a high level of sensitivity.

Since the hardware actuators were in a loose setup, apparatuses had to be attached to several body positions (see Figure 3). Participants were asked to rate those positions and all feedback modalities on a *5-point Likert scale* in terms of *comfort* and *relaxation*.

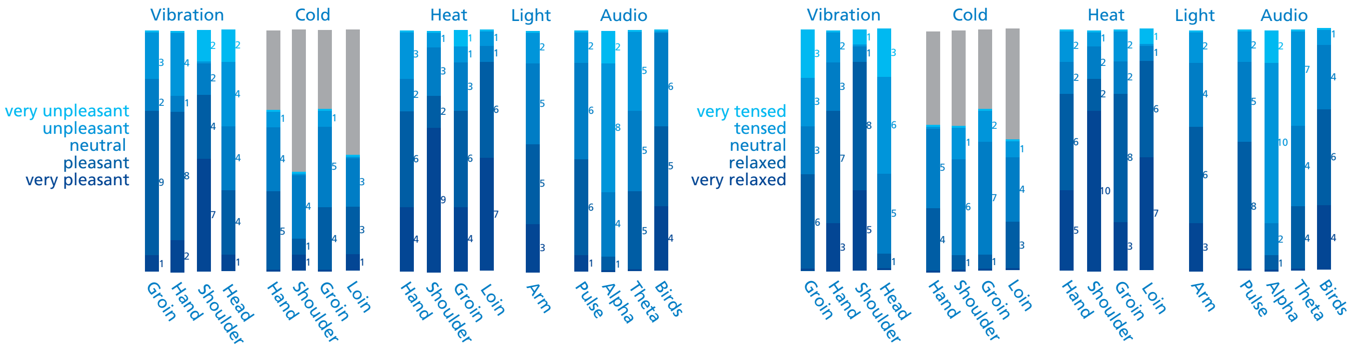

Figure 4. Qualitative results representing the sentiments of 15 subjects. The left part shows how un-/pleasant the feedback has been evaluated. On the right side, we present all ratings on how much the volunteers felt tensed/relaxed while exposed to the feedback.

Results

Vibration Feedback

Comparing the positions with vibrational feedback yielded statistical differences following a one-way ANOVA ($F_{3,42}$=14.16; p<.0001). A Tukey HSD Test suggests that vibration at the shoulder (M=3.03; SD=1.387) was perceived significantly more pleasant than at the head (M=2.86; SD=1.18; p<.01). Further significant differences occurred. Vibration at the head was perceived significantly more unpleasant in comparison to the groin (M=3.53; SD=0.92; p<.01) and hand (M=3.53; SD=1.06; p<.01).

In terms of generated relaxation, a one-way ANOVA again found significant differences ($F_{3,55}$=9.4; p<.0001). Following a Tukey HSD Test, vibration at the shoulder (M=4.07; SD=1.07) was perceived significantly more relaxing than vibration at the hand (M=3.73; SD=0.96; p<.01) and at the head (M=2.27; SD=0.88; p<.01). The effect of relaxation at the head was again worse than at the hand.

Cold Feedback

Surprisingly, about half of our test subjects were barely noticing the cold feedback. Therefore, they did not rate it. Two other participants expressed the opinion of avoiding the application of cold feedback due to the very strange sensation. Consequently, we decided to not consider the cold stimuli, since we cannot provide a valid statement with our collected data.

Heat Feedback

Having a look at heat feedback for several positions resulted in significant differences following a one-way ANOVA ($F_{3,42}$=10.42; p<.0001). A Tukey HSD Test suggests heat at the position of the hand to be significantly less pleasant than heat at the shoulder (M=4.27; SD=1.03; p<.01) or loin (M=4.27; SD=0.88; p<.01). Moreover, heat at the loin is even more pleasant than applying heat at the shoulder or at the groin (M=3.73; SD=1.16; p<.01).

In terms of subjective relaxation, a one-way ANOVA again found significant differences ($F_{3,32}$=7.58; p=.0004). A Tukey HSD revealed applying heat at the loin (M=4.2; SD=1.08; p<.05) or at the shoulder (M=4.4; SD=0.98; p<.01) to be more relaxing than at the groin (M=3.8; SD=0.94). Moreover, applying heat at the hand (M=3.93; SD=1.03; p<.01) seems to be less relaxing than applying it at the position of the shoulder.

Light Feedback

An interesting addition is of course light feedback. Since we could not distribute it on our body, because it would be in line of sight when being attached to the loin or shoulder, we only evaluated it as a light-emitting wrist band. Nine test subjects stated to feel relaxed by an orange light. However, subjects suggested to prefer an indirect light shining on the table. Also, they requested an individual adjustment of illumination, position and intensity.

Audio Feedback

Comparing audio stimuli yielded significant differences following a one-way ANOVA ($F_{3,56}$=10.48; p<.0001). A Tukey HSD Test suggests that the bird sound (M=3.94; SD=0.85) was experienced as more comfortable than Alpha (M=2.27; SD=0.8; p<.01) and Theta (M=3; SD=0.85; p<.05) waves. Still, listening to the user's pulse (M=3.36 SD=0.84; p<0.1) was deemed more pleasant than monotonous Alpha waves.

Looking into differences in the level of relaxation yielded significant differences by a one-way ANOVA ($F_{3,56}$=12.65; p<.0001). A Tukey HSD Test suggests bird sounds (M=3.87; SD=0.92) to be more relaxing than the sound of Alpha (M=2.13; SD=0.74; p<.01) and Theta (M=2.8; SD=0.86; p<.01) waves. Again, the sound of the user's pulse (M=3.4; SD=0.74; p<.01) was more relaxing than the sound of Alpha waves.

Summary

Q1: Overall, the most pleasurable position for vibration was the shoulder, as it was the most relaxing too. We have chosen to apply heat at the loin, since this position was most pleasurable and relaxing. Furthermore, the bird sounds were rated to be most pleasant and relaxing.

Q2: Comparing the LED wristband (M=3.67; SD=0.98) with the bird sounds (M=3.87; SD=0.92), with the heat at the loin (M=4.2; SD=1.08), and with the vibration at the shoulder (M=4.07; SD=1.07) did not show any significant differences following a one-way ANOVA ($F_{3,60}$=0.4; p=0.75). Therefore, we cannot say which feedback is prone to relax the user most.

STUDY 2: STRESS TEST

Based on the findings of our first study, we built a second prototype that provided dedicated feedback at fixed positions. The prototype incorporated two vibrators at both shoulders, two Peltier elements at the loin (left, right), a shining light on the left arm, an LED table light and a sound output via headphones. In addition, sensors such as a Pulse-oximeter and galvanic skin response sensor (GHR) have been installed to calculate the stress level of the user. Following this, the status has been communicated by a colored LED to the subjects in order to visualize the experienced stress.

In this study, we wanted to answer whether the chosen feedback modalities would have a positive impact on the resistance to stress and whether the test subject would improve his task performance with the help of this feedback when exposed to stress.

Research Questions

Q3: Would comfortable feedback have an impact on the task load when coping with stress?

Q4: Would comfortable feedback sustainably relax a user during and after a stressful task?

Method

To answer these questions, we conducted a laboratory study with two conditions in an experimental between-subject-study design:

- Group A (using the prototype's feedback modalities): 16 subjects, 8 of them female (*Mean age* = 29.1).
- Group B (not offering prototype's feedback modalities): 10 subjects, 6 of them females (*Mean age* = 30.4)

Group A had the opportunity to select stimulating modalities after their personal preference when the device visualized an increased stress level. Group B also received a feedback about the individual stress level, however, participants were not allowed to activate any feedback.

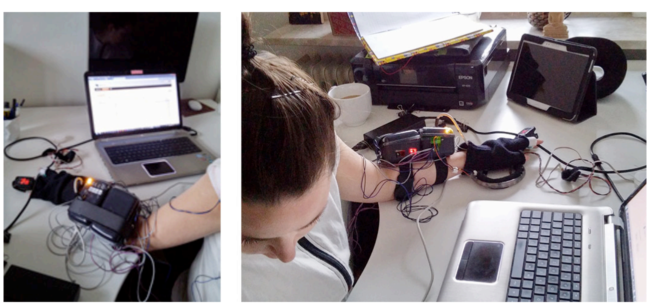

Figure 5. Apparatus – The second prototype consists of an Arduino Uno hidden in a black box and made wearable. We attached a Peltier Element (heat) to loin and a vibration motor to the shoulders. The headphones played birdsongs. A light band was providing a visual stimulus at the arm. An LED visualized the calculated stress level, which is based on a constant heart rate variability (pulse oximetry) and a decreased skin resistance (GSR sensor).

During the experiment, each participant had to solve eight tasks, challenging both their cognitive and motoric skills (for example: building a house of cards, writing a complete letter head, playing an online Jump&Run game, answering logic questions, …). The study took around 45 min, whereby every 5 minutes an alarm clock was ringing, which had to be switched off. If it was not switched off in time, the study leader was taking away the promised reward candies, which had been selected before the study.

To measure the mental task load, all participants were required to fill out a NASA-TLX [6] questionnaire after the completion of each task. In addition, all subjects rated their stress level on a 7-point Likert scale at three different points of time (before, during, and after the experiment).

Results

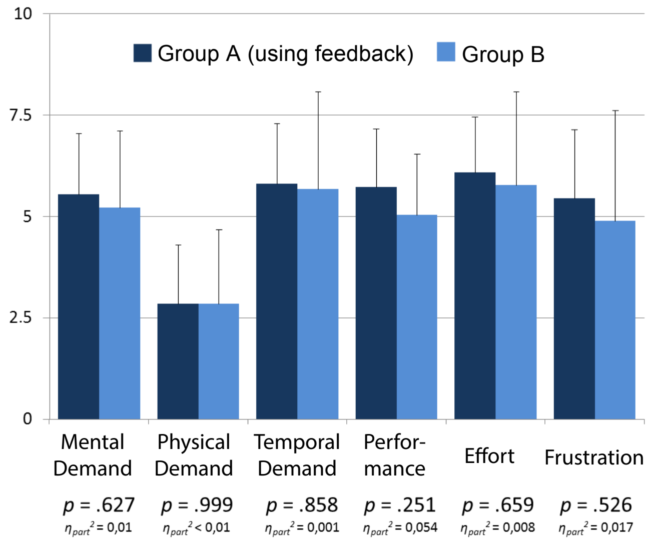

Figure 6. Results of the NASA TLX. Group A (using feedback as a stimuli) vs. control Group B (no feedback): no significant difference found by MANOVA.

For analyzing the NASA-TLX data, a one-way multivariate analysis of variance (MANOVA) has been conducted to compare both groups. As dependent variables, mean values on all tasks have been calculated for all six sub-dimensions of the questionnaire. The analysis reveals a non-significant main effect of the experimental manipulation ($F_{6,19}$=0.254; p=.952), indicating that participants of both groups do not significantly differ in their perceived task load (*Figure 6*).

Q3: Making use of feedback is not physically nor mentally demanding. Unfortunately, the level of stress is not reduced with the use of feedback as it was expected for group A. However, the results also indicate that the user's stress level dramatically decreased while using feedback stimuli. To analyze changes in the perceived stress level, the individual baseline measured at the beginning of the experiment has been subtracted from all values during and after the experiment. The differences have been analyzed by repeated measurements ANOVA with a time point (during and after the experiment) as within-subjects factor, and feedback modalities as the between-subjects factor. The analysis reveals a significant main effect of the within-subjects factor ($F_{1,24}$=10.735; p<.05), indicating that all participants reported a higher stress level during task-processing (*see Figure 7*).

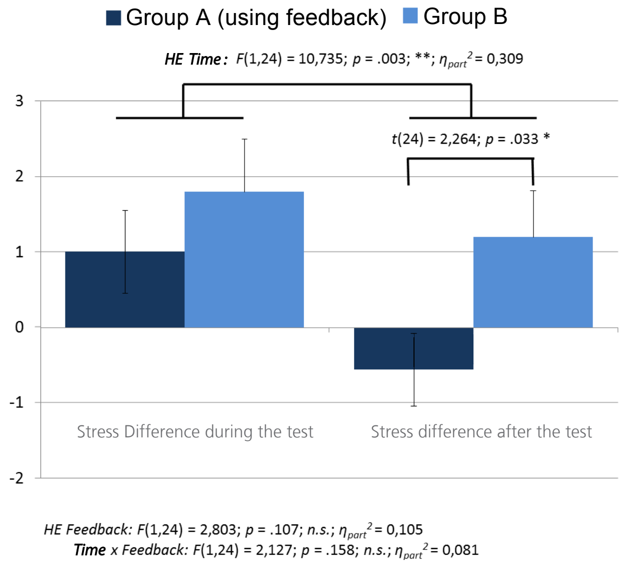

Figure 7. Tax difference with and without rules. This graph shows statistical significance that the subjects are more relaxed with modalities after the test. The subjects without modalities are stressed after the test.

Q4: A non-significant effect is obtained for the between-subjects factor ($F_{1,24}$=2.803; p=.107;), showing that both experimental groups did not significantly differ in their stress level. This result is in line with the NASA-TLX data. However, a post-hoc analysis indicates that only during the experiment no significant differences can be obtained (t=0.904; df=24; p=.375). Asking about the stress level after having completed all tasks at the end of the experiment, the participants of group A produced significant lower stress ratings (t=2.264; df=24; p<.05). This result supports the assumption that the feedback modalities may play an important role in increasing the perceived coping potential and the individual stress resistance.

ENVISIONED SYSTEM

Figure 8. The envisioned system would consist of a shirt and an arm-band. A shirt can be worn under everyday clothes while it would incorporate feedback modalities such as vibration and heat. The wrist-worn device would enable the user to run and adjusted individual relaxation programs, while an expandable OLED display allows for complex input.

In conclusion, we propose a system consisting of a shirt with integrated vibration and heat feedback. For control, the system would require a second device, such as a wristband. The wristband would incorporate an OLED touch screen, which can be rolled out from the side. In addition, the wristband should provide an always-visible display, informing the user about his current state, such as level of stress. Three minimalistic buttons would trigger predefined relaxation programs. This allows the user for a quick and easy mobile operations while being on the go. Although the wristband is the controller, we can also integrate feedback here, such as a sound output or a warming of the wrist.

CONCLUSION & FUTURE WORK

In this paper, we presented WeaRelaxAble, a wearable system providing various kinds of feedback to relax the user and to enhance the individual stress resistance. Two Arduino prototypes were developed and evaluated. We evaluated several feedback modalities and found adequate body positions for providing on-body feedback. In the end, we came up with an envisioned concept, a wrist-worn device, capable of controlling several actuators integrated into a shirt. The expected design of the system works with an explicit input triggered by the user. Beyond that, we argue that it would be interesting to also evaluate an implicit system, which works autonomously while processing the sensed user's state. We suggest that when users become aware of the meaning of a triggered feedback, it might increase their perceived level of stress. This question of implicit feedback is an interesting point for the further development of the presented approach.

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