Towards Pressure-Based Feedback for Non-Stressful Tactile Notifications

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MobileHCI '17, September 4–7, 2017, Vienna, Austria.
ACM ISBN 978-1-4503-5075-4/17/09
https://doi.org/10.1145/3098279.3122132

Abstract
Smartphones, wearables, and other mobile devices often use tactile feedback for notifying users. This feedback type proved to be beneficial since it does not occupy the visual or auditory channel. However, it still can be distracting in other situations such as when users are already stressed. To investigate tactile feedback patterns which do not increase the user's stress level, we developed two wrist-worn prototypes capable of providing tactile feedback (i.e., vibrotactile and pressure-based feedback). Further, we conducted a user-study with 14 participants comparing both feedback types.The results suggest that vibrotactile feedback increases the user's stress level more, compared to pressure-based feedback particularly applied when the user currently has a low stress level. Consequently, we present implications for designing notifications for mobile and wearable devices.

Author Keywords
Affective Computing; Tactile Feedback; Mobile Computing; Notifications.

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

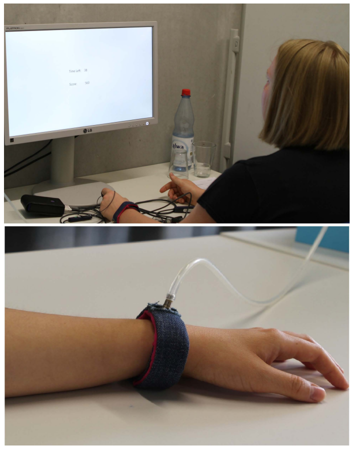

Figure 1: Participant put under stress by mental arithmetic tasks during the recording of electrodermal activity (left). Wristband prototype build to provide pressure-based and vibrotactile feedback (right).

Introduction and Related Work

The number of notifications is continuously increasing. In particular, mobile devices such as smart watches or smartphones generate 65 notifications on average per day [18]. These notifications are communicated via visual, auditory, and tactile cues based on the user's current situation. For example, during meetings, users prefer tactile feedback while auditory notifications are desirable when the user is at home and placed his phone somewhere. Occasions in which tactile feedback is used, are mainly characterized by the fact that the user is highly engaged in other tasks (e.g., meetings, presentations) and, thus, might be easily distracted and stressed by incoming notifications.

Besides vibrational feedback as known from consumer devices, research proposed different tactile feedback methods that can be integrated into mobile and wearable devices. Examples include simple tactile stimulation via tapping, dragging, squeezing, and twisting [16, 24]. Additionally, pressure-based feedback yields advantages such as unobtrusiveness [19]. There are also other approaches using Electrical Muscle Stimulation [21] or changes in temperature [23]. These methods are designed to gain the user's attention as fast as possible. As a performance measure, research therefore investigates the time needed for perceiving the feedback cue. In contrast, we investigate how we can generate a tactile stimulation pattern which induces less stress to the user. We thereby focus on pressure-based stimulation as well as vibrotactile feedback as state of the art. Alvina et al. explored spatiotemporal vibrotactile patterns on different body parts and confirmed it's recognizability [2]. In our work, we investigate how tactile feedback can be designed to suit stressful situations deriving the feedback pattern from physiological signals.

Consequently, we contribute (a) a concept for deriving tactile stimulation patterns from physiological signals, (b) the development of two wrist-worn stimulation giving prototypes, and (c) a preliminary as well as an user study exploring and comparing different tactile stimulation patterns.

Towards Stress Considering Feedback

Current tactile feedback methods are build to acquire the user's full attention instantly. While this makes perfectly sense in use cases which require immediate user intervention (e.g., incoming phone calls), other notification scenarios might not require immediate response (e.g., incoming notifications from social media). In these cases, the feedback can induce stress to the user. Taking this into account, we explore different strategies to create a feedback that does not induce a high level of distraction and discomfort and is therefore suitable in stressful situations.

Since pressure is easily perceived by the peripheral receptors [13] and has been explored as an alternative feedback mechanism most recently by Pohl et al. [20], Wang et al. [27], and Zheng, Su, and Morrell [28], we chose pressure-based feedback. We also used vibration because of its pain relaxation enhancing function [12, 17]. Further, vibration feedback is widely known from smartphones, smartwatches, fitness trackers, and other wearables.

Applications

Perceiving stressful moments can be found almost everywhere in everyday life. Due to this omnipresence of stress, communicating feedback in stressful situations in unobtrusive ways gains importance. Given the described conceptual background, we see multiple promising application scenarios where alternative tactile feedback for user notifications is needed to prevent the increase of the user's stress level. Next, we present two exemplary use cases:

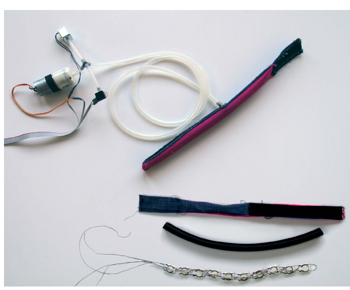

Figure 2: Wristband prototypes build to provide tactile feedback: Pressure-based (top) and vibrational (bottom) feedback.

Giving Presentations
The first time one gave a presentation in front of an audience, usually feelings like nervousness or even anxiety came up. These are often accompanied by physiological reactions such as sweaty hands, shaky knees, or a trembling voice. Imagining that an incoming phone call elicited a constant buzz on the user's smart watch, distraction and eventually a lack of concentration would be triggered. Hence, the physical arousal increased which result into stress, amplifying the described physiological reactions. In worst case the user is trapped in a vicious circle of mental and physiological stress.

Having Job Interviews
Further, there are some occasional events that take place from time to time such as job interviews. Sitting in front of one or more unknown persons, knowing that they have certain expectations and being conscious about the potential consequences of the job interview can easily lead to feelings of unease and tenseness. The perception of being stressed can even result into lower self-confidence regarding the hiring [5]. Distraction from feedback giving devices would provoke the previously described negative effects and again result into physiological reactions to stress.

Tactile Stimulation Wristbands

To investigate the influence of the different types of tactile feedback on the user's stress, we built two prototypes of wrist-worn wearables (see Figure 1, 2). First, we developed a wristband capable of providing vibrotactile feedback as known from fitness trackers and smartwatches. Second, we developed a wristband with a novel type of tactile feedback leveraging pressure-based feedback similar to the work of Pohl et al. [19]. Both wristbands have the formfactor of watch-straps (approx. width: 2.5 cm; length: 30 cm). We used jeans fabric on the outside and an elastic fabric on the inside. Each wristband is filled with a bicycle tube, which we cut to the right length. Finally, we vulcanized each wristband on both ends. We connected both wristbands to an Adafruit Metro Mini 328 to trigger the feedback.

Feedback Types
Our prototypes allowed us to precisely control when and how much pressure or vibration is applied. Therefore, we were able to design two signals similar to physiological signals of humans. These signal patterns are periodically repeated. The first signal is derived from the pulse. A single impulse is given in every time frame. In contrast, the second signal is derived from the human heart beat. It consists of two consecutive short stimuli. The frequency of both signals is determined by the resting pulse of the user (i.e., number of heart beats per minute).

Pressure-based Stimulation Wristband
The pressure-based wristband fills the tube with air which in return applies pressure to the user's wrist. To infuse the pressure wristband with air, we used a pressure pump and valve from a disassembled AEG BMG 5611 blood pressure meter [1]. These are attached to the bicycle tube inside the wristband. Accordingly, feedback is applied by filling the wristband with air.

Vibrotactile Stimulation Wristband
The vibrotactile wristband contains ten shaftless vibration motors. To maximize the wearing comfort, we attached each vibration motor to a small 3D printed case with a slight curvature towards the wrist. The motor cases were loosely connected via threads which remain flexible and keep them at a constant distance of 20 millimeters. We inserted the vibration motor assembly into the bicycle tube, so users could not directly feel the motors on their skin but perceive the tactile stimuli.

Figure 3: Participant rating comfort and discomfort for the exploration of tactile feedback patterns.

If you experienced ache, pain, discomfort, how uncomfortable was this?	If you experienced ache, pain, discomfort, did this interfere with your ability to work?
Slightly uncomfortable ☐ Moderately uncomfortable ☐ Very uncomfortable ☐	Not at all ☐ Slightly interfered ☐ Substantially interfered ☐

Figure 4: The two items taken from the Cornell Musculoskeletal Discomfort Questionnaire [9] assessing perceived discomfort.

Preliminary Study: Exploring Tactile Feedback

Prior work outlines that even minor adjustments in frequency, intensity, and the feedback pattern itself can lead to different feedback perceptions [4]. Therefore, we conducted a preliminary study exploring comfortable feedback patterns for both, vibrotactile and pressure-based stimulation.

We recruited 10 participants aged between 22 and 42 ($M = 29.2$, $SD = 6.4$) via personal acquisition. In a within-subject design we applied two feedback methods (pressure and vibration), two feedback pattern (pulse and heartbeat) and three feedback frequencies as independent variables balanced according to Latin Square. The frequencies were calculated by taking 50%, 75%, and 100% of the resting pulse rate which we measured with a MPXV5050GP pulse monitor for each participant before presenting the different patterns. After attaching the prototypes to participants' left hands, we then applied the 12 different tactile feedback stimuli for 10 seconds intermittent by five seconds break.

Determining the most suitable feedback pattern, we measured discomfort using two items depicted in Figure 4 from the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) [9]. Furthermore, we asked the participants how comfortable they perceived the tactile stimulation on a Likert item scale ranging from 1 (not comfortable at all) to 6 (very comfortable) (see Figure 3).

The results depicted in Figure 6 show that the heartbeat pattern with 50% frequency has been perceived most comfortable for pressure ($M = 4$). For vibration also this pattern has been perceived slightly more comfortable ($M = 4.3$) however not as comfortably as the pulse pattern with 100% frequency. For both, pressure and vibration, the heartbeat pattern with 50% frequency has been perceived least discomfortable ($M = 1.1$ each) (see Figure 7).

Due to its high subjectivity we wanted to find a compromise between 'most comfortable' and 'less discomfortable', hence we chose the latter as the final tactile stimulation pattern for our main study.

Main Study: Tactile Stimulation under Stress

In the main study, we investigated the effect of different feedback methods on the user's stress level of pressure-based feedback and compared it to vibrotactile feedback as well as to no feedback, which served as our control condition. Thereby, we focused on three different stress levels (i.e, easy, medium, and difficult) and assessed physiological data as described in the following.

Measures and Stress Elicitation Task

In our study, we recorded the electrodermal activity (EDA) rate which indicates the activation of sweat glands related to activation in the sympathetic nervous system. An increase in the EDA indicates an increased stress level as has been shown in prior work [6]. To investigate the influence of tactile feedback on the participants' stress level, we used a verbal mental arithmetic task (MAT) [3]. In this task, participants count verbally backwards in steps of seven which proved effective in previous research [8, 10, 11, 22, 25].

Participants and Procedure

We recruited 14 participants (6 female, 8 male) aged between 20 and 30 ($M = 25.4$, $SD = 3.3$) via university mailing lists. Upon arrival in the lab, we explained the study purpose and all participants filled in an informed consent form as well as demographic questions. Afterwards, we attached two sensors on the participants' index and middle finger tips recording EDA, for which we used a Mindmedia NeXuS biofeedback kit 4 [15].

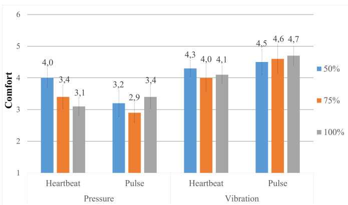

Figure 6: Mean results for the one-item Likert scale on perceived comfort. It shows that for pressure the heartbeat pattern with 50% fequency has been perceived best. For vibration the pulse pattern has been perceived slightly better than the hearbeat.

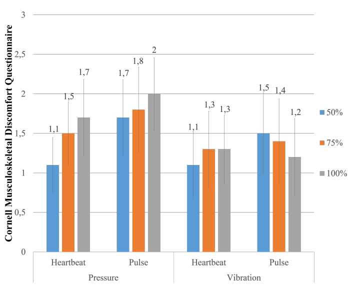

Figure 7: Mean results for the self-rating regarding perceived discomfort using the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) [9]. It shows that for both, pressure and vibration, the heartbeat pattern with 50% fequency has been perceived less discomfortable.

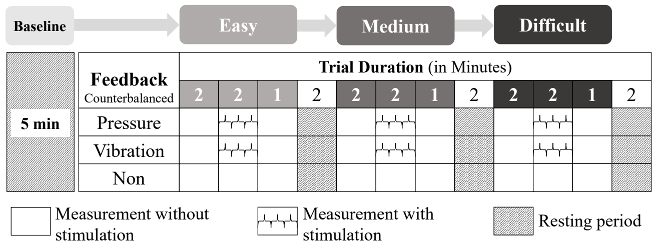

Figure 5: The study design consisted of three trials for each participant, ranging from easy over medium to difficult. For each difficulty level we applied all three feedback method in one trial each and in counterbalanced order.

For the MAT, we chose three different ranges of difficulty to elicit ascending stress levels, presenting random numbers: easy (two-digit numbers), medium (three-digit numbers), and difficult (four-digit numbers). From the given starting number the participants needed to count backwards in steps of seven.

We provided feedback to the participant by showing the current score on a 17" display (cf., Figure 1). For each correct answer, the score was highlighted in green color and increased by 10 points, whereas the score was highlighted in red color and was penalized by not increasing in case of a mistake. We conducted three different sessions increasing the difficulty level from easy over medium to difficult. We did deliberately not counterbalance the difficulty levels' order for preventing carry-over effects.

Each session for a specific stress level consisted of three different trials (see Figure 5). We derived the study design from [14] and [26]. In each trial, one feedback method (pressure, vibration, no feedback) was applied in counterbalanced order according to a Latin Square. The study took about 90 minutes including a 5-minute baseline trial at the beginning and nine 5-minute trials (3 feedback types * 3 stress levels) intermittent by 2-minute breaks. During the study, we showed a 60 seconds-countdown on the display. After 60 seconds, the participant was told a new number to continue with the MAT until the trial was over.

Results

We averaged the EDA values of the 2 minutes stimulation phase for each participant and thereby calculated one mean value for each participant. The results show that EDA increases during the stimulation phase compared to the baseline. An overview of this increase is depicted in Figure 8. Comparing the rises of the different feedback patterns among all participants, it can be observed that providing no feedback at all has the lowest deviation from the initial baseline measurement ($M = 11\%$ easy, $M = 15.9\%$ difficult) followed by pressure feedback ($M = 13.5\%$ easy, $M = 17.4\%$ difficult). Vibrotactile feedback showed the highest deviation from the baseline and therefore the highest increase in EDA ($M = 17.3\%$ easy, $M = 18\%$ difficult). A two-factor ANOVA did not reveal statistically significant differences for the tested tactile stimulation and for the difficulty level on EDA.

Looking at the medium and high stress level, vibrotactile and pressure-based feedback slightly increases the EDA compared to not providing feedback. In contrast, the vibrotactile feedback elicits the greatest increase of EDA for the low stress condition which was induced by the difficulty level 'easy' compared to the other feedback patterns. Hence, it becomes obvious that under low mental stress the effect of vibrotactile is greater considering the low EDA value for no feedback in the same condition. Over all three conditions one can see that stress is almost constantly high when vibrotactile feedback is provided. In contrast, pressure-based feedback leads to lower EDA values when the user is put under low mental stress.

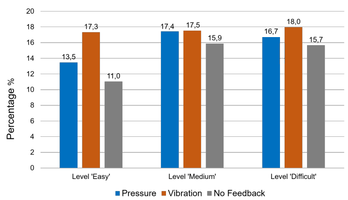

Figure 8: The deviations from the baseline measurements during the stimulation phase. High values indicate increasing electrodermal activity which signifies increased stress.

Implications

Pressure-based Feedback for Low-Stress Situations

The results of our study show that the user's stress level greatly increases as soon as vibrotactile feedback is provided. This finding is also supported by Haller et al. [7] who report that vibrotactile feedback had been perceived more mentally demanding. In contrast, pressure-based feedback leads to lower ascents of the stress level. This shows that particularly in situations in which the overall stress level is rather low, providing pressure-based feedback is beneficial.

Slow Feedback, High Comfort Participants rated in the preliminary study feedback with a lower frequency as more comfortable (i.e., 50% of the pulse more comfortable than 75% and 100%). Thus, feedback considering the user's stress level, should follow a slow rhythm. According to comfort, Pohl et al. [20] investigated the suitability with respect to a longer usage period in an 1 hour experiment. During that time of mobile usage, participants did not report 'feeling inhibited or annoyed by the device'. However, this finding gives evidence that pressure-based feedback is not perceived discomfortable, some issues are remaining unclear e.g how people would react to it for a couple of hours. These and other questions could be answered in future works as discussed in the following.

Limitations and Future Work

This work provides a first assessment of the influence of tactile feedback methods on the users' stress level. We thereby focus on two particular feedback methods, namely vibrotactile and pressure-based feedback. We used these feedback patterns since related work proposes that both methods can be used in a way that they consider the user's stress level. In the future, investigating further feedback methods will provide a more detailed understanding of which feedback methods performs best with regards to the influence on the user's stress level. We used a controlled laboratory study setup to be able to control the different stress levels and measure the user's physiological reactions limiting confounding variables. Future work could validate these results in a real world setting since this could provide larger insights whether our concept of pressure-based feedback for stressful situations could be applied to real-world scenarios. This could be achieved by combining the proposed feedback methods with smartphones and eventually in the presented use cases.

Conclusion

In this paper, we compare different types of tactile feedback with respect to their impact on the user's stress level. We show that vibrotactile feedback has a greater impact on the user's stress level, particularly in low-stress situations, compared to pressure-based feedback. This evaluation is a first step towards understanding the impact of different tactile feedback of mobile devices methods on users. While most feedback methods are evaluated with focus on key performance indices such as reaction time, taking the stress level of the user into account opens up another important evaluation perspective. This is particularly important in mobile settings when the user is already engaged with other tasks. When looking at the increasing number of notifications focusing on user-centred approaches, designing tactile feedback methods for mobile devices gains more importance.

Acknowledgments

This work was partly conducted within the Amplify project which received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 683008).

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