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Augmenting interoceptive awareness with off-the-shelf sensors using visuo-haptic emotional stimulus

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Abstract

Wearable sensing technologies allow us to monitor and track a wealth of information about bodily states. Tracking applications rely on abstract numerical or graphical visualizations to make this information accessible to us. However, these visualizations can be hard to interpret, and even be harmful to already vulnerable groups. Hence, we propose to give feedback in the form of an enhanced heart rate interoception and an embodied artificial agent. This method relies on the person's inherent understanding of their own body. It is a subtle and more natural way to gauge the meaning of off-the-shelf sensors' feedback. A wearable pet prototype that presents emotion through visuo-haptic feedback is evaluated in a match and a mismatch group. Participants in both groups answered self-report and perceived affect of the interoceptive feedback without significant differences. However, the groups' perceived closeness to the pet differed significantly.

Keywords:

Interoception; Haptic feedback; Well-being; Self-quantification; Emotional stimulus.

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1 Introduction

Wearable sensing technologies have enabled us to monitor our bodily states and, given some self-discipline, improve our health [9]. The entry device for most people, and often central hub for data analysis, is their smartphone [2]. Smartphones can measure a variety of activities such as sleeping, walking, cycling, driving a car, or taking the train by analyzing data from built-in sensors such as acceleration and GPS. Additional watch-type fitness trackers are able to record heart rate, heart rate variability, electrodermal activity, body temperature, and breathing to give feedback about stress levels and overall health [7], [14]. To convey current progress during tracking and results of self-set improvement goals, companion applications rely on abstract numerical or graphical visualization, such as line graphs, bar plots, or progress bars.

This way of representing data does not work equally well for all user groups and can even be harmful to already vulnerable groups [6]. Recent works started to make use of interoception in an attempt to provide an alternative for giving feedback in a subtle and easier to comprehend way [5]. Interoception, as described in [3], is the perception and integration of autonomic, hormonal, visceral and immunological homeostatic signals that collectively describe the physiological state of the body. Our work follows this trend and presents a prototype of an embodied artificial agent representing real-time user data by measuring heart rate and providing interoceptive feedback through haptic stimulation in a single wearable. The objectives of the study are to investigate, (1) whether a human being can recognize the haptic stimulation synchronized with a visual emotional stimulus as heartbeat; (2) if this stimulus had an impact of their emotions; and (3) if the synchronization of the artificial agent's affective state and the user's affective state can lead to a closeness between the user and the artificial agent. The emotional state of the participants was elicited using videos. This allowed us to evaluate the interoceptive feedback of the proposed device when the feedback matched or mismatched the elicited emotion. The motivation of this study is to increase interoceptive awareness allowing to design wearables capable of tracking the health state of the user providing subtle visuo-haptic feedback. In addition, inducing a feeling of closeness between the users and their artificial agents may enhance the engagement of the user with this subtle feedback.

2 Related work

Interoception is defined as the ability to correctly perceive sensations from within the body [16]. Interoceptive cues can be represented as exteroceptive stimuli from the environment using haptic patterns in a private and unobtrusive manner using wearable devices. Several works proposed to use haptic stimuli to increase interoception in the user and guide him towards a well-being health state. Azevedo et al. proposed a wearable device that delivers heartbeat-like tactile stimulation on the wrist [1]. They tested whether the use of their wearable device would have a calming effect during the anticipation of public speech. This task typically induces high anxiety. They found that participants that used the device displayed lower increases in skin conductance responses relative to baseline and reported lower anxiety levels compared to the control group. Xu et al. provided haptic stimulation simulating participants' slowed-down heartbeats or no stimulation while they engaged in socially stressful tasks to examine whether participants reacted differently depending on their interoceptive accuracy [15].

Results showed that when receiving the stimulation, participants with higher interoceptive accuracy showed less increased heart rate than participants with lower interoceptive accuracy. Papadopoulou et al. proposed a wearable device that produces rhythmic haptic action (warmth and slight pressure along the arm) to promote calmness and reduce anxiety [8]. Through a controlled pilot study, the authors demonstrated that the pace of haptic action of the sleeve can influence the participants' breathing rate and perception of calmness. Although several works have already shown that haptic stimulation can increase interoception to promote well-being, none of them explored the use of interoceptive patterns in addition to visual representations of affect, such as facial expressions or an artificial agent animation.

3 Method

This study was implemented in two steps. First, a wristband similar to previous work [10] was improved and adapted to the users. The main difference to [10] is that the heart rate, measured from the user, was used as basis for the real time vibration feedback instead of predefined static vibration speeds. Second, the wristband's vibration was matched to a web application in which an emotional visual stimulus, a panda pet agent, displaying emotions consistent or inconsistent with the emotion of the user. The panda's emotions were complemented with haptic vibrations simulating the pet's heart, and mapped to the user's heartbeat. Emotions were elicited with videos that were presented to the user.

3.1 Capturing the Heart Rate and Implementation of the Haptic Stimulus

A wristband made with flexible fabric was fitted with three Xiaomi Mi 2 fitness band cores (**Figure 1**). These fitness bands have a coin vibration motor used for alerting the wearer. They were connected via Bluetooth to a laptop (NEC Lavie Hz750/C) running the Robot Operating System (ROS) Kinetic on Ubuntu (16.04 LTS). The mapping of the vibration to the measured heart rate was done via a custom python script. Like previous work, the vibration pattern simulated the heart's beating $S1$ and $S2$ which corresponds to the QRS complex and T-wave of the heart's electrical activity [12]. The pattern was produced three times, representing three cardiac cycles. The duration of each cycle was fixed to t_{base} = $100ms$ and the time between each cycle is calculated based on the user's heart rate (HR) as t_{rep} = $60/HR_{in}$. The time between $S1$ and $S2$, $tQ{-}T$ was set as 15% of t_{rep}, where HR_{in} = $BPM * x$ is one of four interoceptive patterns, calculated by multiplying the user's base HR by several factors: x = (0.5, 1, 2).

Figure 1. A Xiaomi Mi band 2 sensor (right image) with the inside of our wristband prototype capable of accommodating three of the Xiaomis using three pockets (left image).

3.2 Implementation of the Visual Stimulus and Synchronization with the Heart Rate

A pet agent was designed to fit nine zones of the circumplex model of affect. These zones were all combinations of three arousal levels (low, neutral, and high) and three valence levels (low, neutral, and high). The pet was a caricaturized anthropomorphic character as reflected in the pet's ability to show human-like affective displays.

Two iterative online surveys were used to (1) refine the visualizations, and (2) ensure that each visual representation conveys a specific emotion to the user (**Figure 2**). As shown in **Figure 2**, the animations at the bottom line with low arousal have a playback coefficient of 0.5 times their normal speed (heart rate of the user). Pet representations in the middle row represent normal arousal and are played back at normal speed. The animations in the top row represent high arousal and are presented at twice the users heart rate. The same is true for the vibrations that were sent to the user. Only the animation of the pet in its emotional state had an animation speed based on the heartbeat of the user. The state change animations have a fixed speed. This is because the animations of change of state are much shorter that the emotional state animation.

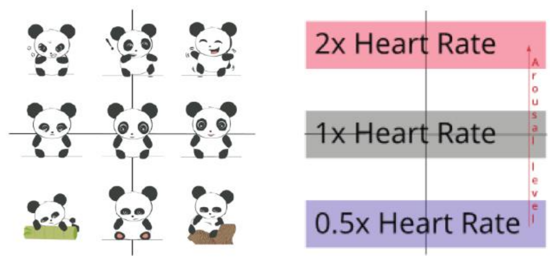

Figure 2. Animation of the digital pet emotional state in relation with the vibration speed.

4 User study

Two groups of five participants, a total of 10, volunteered to participate in our study (three female, average age = 30.7 ± 7.38 years old). The participants gave informed consent to participate. The participants were also informed that they can take a break or interrupt the session at any time. One group received interoceptive feedback and animations of the pet agent that matched the emotion elicited by the video, while the other group was presented with mismatched feedback.

The participants were invited to wear the wristband prototype which included the three Xiaomi sensors (**Figure 1**). First, participants answered the STAI questionnaire. This was only used to make the participants believe that the pet was created from their answers to this questionnaire. In reality, the same pet was used for all participants. This was chosen to boost their sense of ownership and to foster a sense of group belonging with the pet. Next, participants were asked to watch nine emotion elicitation videos from two emotion-eliciting databases publicly available (FilmStim database [13]; Emotional Movie Database (EMDB) [4]). Similarly, to the visual representations, the nine videos were selected to match low, neutral, and high valence and arousal levels, and to match each one of the nine pet visualizations (Figure 2). After each video, they were asked to report their affective state using the Affect Grid [11]. Next, the animated pet appeared along with the respective interoceptive vibration pattern calculated in real-time. After watching the pet animation, they were asked to report how the pet felt based on the Affect Grid. At the end of the experiment, participants were asked to answer the Inclusion of Other in the Self (IOS) scale to measure how close they felt with the pet agent.

5 Analysis and results

Differences were observed for self-reported arousal between the between match (Mdn=0) and mismatch (Mdn=-1) groups, and for self-reported arousal (Mdn=-1) and perceived affective arousal state of the pet (Mdn=0) in the mismatch condition. Wilcoxon rank-sum tests indicated that these differences were statistically not significant. Table 1 shows the results for all performed Wilcoxon rank-sum tests. Individual participant responses are shown in **Figure 3** and Figure 4.

We performed a Welch's t-test to confirm whether the closeness of the user to the pet differed between individuals of the match and mismatch groups. The mean IOS scores were 4.8 (SD = 0.39) for the match group, and 3.4 (SD = 1.02) for the mismatch group. This difference, 2.4, was statistically significant, $t(8) = 2.56$, $p = 0.049$.

Table 1. Results of the Wilcoxon rank-sum tests.

Description	Z	p
Arousal of self-report between groups	-1.39	0.16
Valence of self-report between groups	-1.23	0.22
Pet's arousal rating between groups	0.76	0.45
Pet's valence rating between groups	-0.29	0.77
Arousal in match group between perception of the pet's affective state and self-report	-0.82	0.42
Valence in match group between perception of the pet's affective state and self-report	-0.44	0.66
Arousal in mismatch group between perception of the pet's affective state and self-report	1.49	0.14
Valence in mismatch group between perception of the pet's affective state and self-report	0.50	0.61

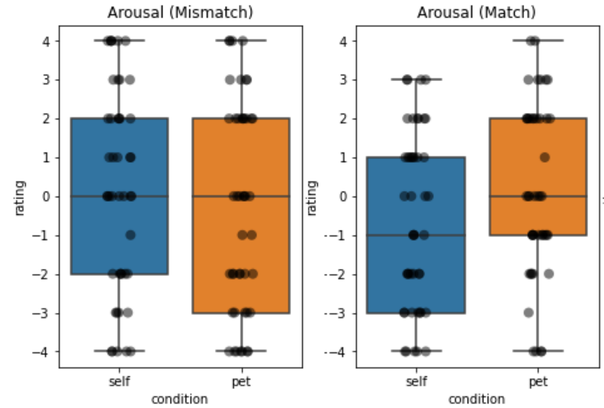

Figure 3. Comparison of the self-reported and pet-attributed arousal in the groups with matched and mismatched vibration feedback.

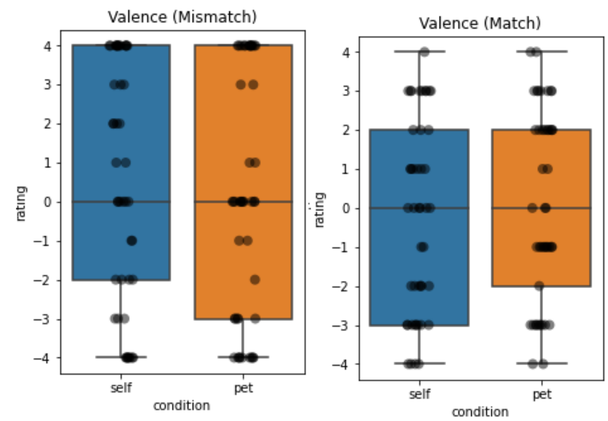

Figure 4. Comparison of the self-reported and pet-attributed valence in the groups with matched and mismatched vibration feedback.

6 Discussion and future directions

We presented a prototype that measures heart rate and provides interoceptive feedback through haptic stimulation in a single wearable. Furthermore, we assessed to what extent the device is able to communicate an emotion through a combination of interoceptive and visual feedback. The results suggest that using a combination of visual and haptic stimulation can effectively communicate different arousal and valence levels. At the same time the interoceptive perception of the user was enhanced. The results showed that even though participants in both groups rated valence and arousal of the pet agent similarly to their self-rating, their perceived closeness with the pet was significantly higher. This closeness can be used to create a feeling of empathy between the user and his/her agent increasing the engagement of the user with the wearable. Finally, these results suggest that visuo-haptic channels can be used as an alternative way to increase self-awareness of the users. Future work with more participants should investigate whether the observed difference in closeness was caused by the pet agent or the haptic interoceptive feedback. It will also be of interest to increase closeness ratings with the pet using customization options (e.g. choice of the pet, personality of the pet, etc.). Finally, a future version of the prototype should integrate the visual channel (pet display) into the wearable instead of displaying it on a web application.

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