PiHearts: Resonating Experiences of Self and Others Enabled by a Tangible Somaesthetic Design

Ilhan Aslan

Human-Centered Multimedia Lab, Augsburg University
Huawei Technologies Duesseldorf GmbH, Munich
Research Center, Germany
ilhan.aslan@huawei.com

Andreas Seiderer, Chi Tai Dang, Simon Rädler,
and Elisabeth André

Human-Centered Multimedia Lab, Augsburg University
Germany
lastname@hcm-lab.de

ABSTRACT

A human's heart beating can be sensed by sensors and displayed for others to see, hear, feel, and potentially "resonate" with. Previous work in studying interaction designs with physiological data, such as a heart's pulse rate, have argued that feeding it back to the users may, for example support users' mindfulness and self-awareness during various everyday activities and ultimately support their health and wellbeing. Inspired by Somaesthetics as a discipline, we designed and explored multimodal displays, which enable experiencing heart beats as natural stimuli from oneself and others in social proximity. In this paper, we report on the design process of our design PiHearts and present qualitative results of a field study with 30 pairs of participants. Participants were asked to use PiHearts during watching short movies together and report their perceived experience in three different display conditions while watching movies. We found, for example that participants reported significant effects in experiencing sensory immersion when they received their own heart beats as stimuli compared to the condition without any heart beat display, and that feeling their partner's heart beats resulted in significant effects on social experience. We refer to resonance theory to motivate and discuss the results, highlighting the potential of how digitalization of heart beats as rhythmic natural stimuli may provide resonance in a modern society facing social acceleration.

CCS CONCEPTS

• **Human-centered computing**;

KEYWORDS

Tangible design; Social interaction

1 INTRODUCTION

A healthy human body is arguably an intelligent, self-regulating, and self-maintaining organism, which requires little explicit attention to function and enable joyful everyday experiences. However, as a consequence of unhealthy behavior, stress, age, injuries and illnesses of various sorts, etc. our bodies will need attention to ensure quality of life. We believe that technology may assist users in both ubiquitously observing their bodily behavior and enabling healthy interactive experiences.

Since digitalization is in the process of transforming the health domain, it is not surprising that the body of related work is increasing rapidly in terms of the diversity of explored applications, user experiences, technologies, modalities and interaction designs. For example, Dang et al. [7] have recently proposed to use an affective mirror in a smarthome setting to feed back a machine interpretation of a user's expressed emotion in addition to mirroring their physical image. They argue, for example, that feeding back to users how their affective states could be interpreted by the "outside world", allows users to become aware of their emotional expressions and potentially optimize their self-presentation. To date, a multitude of data display technologies and techniques have been studied to inform and enlighten users about their own behavioral patterns and physiological and mental states, including tangible displays to feed back heart beats or breathing patterns to users through animating physical artifacts. For example, Aslan et al. [1] have argued that a breathing plush toy or a beating artificial physical heart provide more natural and direct mappings of real heart beats and breathing movements than screen-based solutions. A part of their exploration was an inquiry with experts in mindfulness based stress reduction (MBSR) therapy [22]. Those experts suggested that the main benefit of utilizing mobile and multimodal displays could be in addressing the growing diversity in users and in application contexts (e.g., children in schools or inmates in prisons), enabling different user groups access to mindfulness practices and its benefits, such as enhanced wellbeing [31] or stress reduction [35].

Mobile technology, such as wellbeing apps on smartphones have been gaining popularity. They are aiming to provide on the go health effects similar to effects provided by traditionally analog mindfulness practices, which have only been available to a group of dedicated and skilled individuals who often practice in environments and spaces specifically designed for meditation and mindfulness training. Indeed, the surrounding world has an influence on users' experiences and their cognitive processes. For example, Hansen et al.[9] provide a detailed survey of beneficial therapeutic effects of "Shinrin-yoku" (forest bathing), which is based on the idea of exposing people to natural stimuli.

Hartmut Rosa [34] who has recently introduced "resonance theory" to explain our relationships to the world argues that a modern "accelerating" world (e.g., a world in which we meet more and more people and own things for shorter times) increasingly fosters experiences of alienation and that people strive towards (experiences of) resonance. He further explains that the increase of interest in yoga, wellbeing and mindfulness application, etc. could be interpreted as signs of social acceleration and people looking for resonance. Arguably, experiences of resonance can be achieved by assisting users in strengthening their relationships to their environment, other people, and themselves. We believe that an artificial physical heart that looks like and beats like a real heart has the potential to enable such resonating experiences by either feeding back users their own heartbeat or feeding them back a person's heartbeat to whom they relate to. This assumption is based on the fact that a heart beat as a natural stimuli is something that accompanies our living bodies throughout our existence potentially starting with experiencing and synchronizing with our mothers heart before we are born and carrying our heartbeats throughout our life times and sharing it with friends, family members and partners through hugs, touches, etc. Our hearts move and enable movement and as Sheets-Johnestone puts in in her book on the primacy of movement are a sign of life. *"We come into the world already moving. We are indeed either movement-born or still-born"* ([36], p22).

In this paper, we present PiHearts, a handheld design that aims to augment everyday experience by utilizing a multimodal feedback style. PiHearts enable two feedback conditions. It can feedback ones own heart beat as a "natural" stimuli or it can feed back an other person's (e.g., a partner's) heart beat as a "natural" stimuli during a mundane everyday activity, such as watching a movie together.

1.1 Related Work

The research on user experiences with tangible and embodied interfaces that incorporate heart rate can be assigned to one or more of the categories games, art, awareness, and shared or remotely shared experiences. In the following, we briefly discuss an overview of the works most relevant to our paper.

In terms of tangible games, the heart rate is mostly used straightforwardly within the interface, for example to inform a player about their nervousness as demonstrated by Dang et al. in "Surface-Poker" [6], or to adjust or influence game parameters based on the heart rate [18]. For virtual reality games Harley et al. [10] employed tangible objects in order to improve tactile sensations and experiences beyond those of a classical VR hand-held controller. In one of the tangible objects, i.e., a hollow raccoon toy, the heartbeat was created by an embedded vibration motor. Magielse et al. [29] included the heart rate in an outdoor pervasive game in which the tangible game controllers created beep sounds resembling opponent's heart rate as soon as an opponent player comes in proximity.

Considering the art-context, tangible objects make use of heart rate as biofeedback to create physical experiences. For example, Loke et al. [27] employed the *Bodyweather performance methodology* and realized a live-art installation in which a participant's breathing and heart rate was mediated through sonification in order to experience those together with an awareness of "*self, body and the world*". Another artistic experience was presented by Nunez-Pacheco et

al. [30], who investigated "*technology-mediated self-reflection on the body*". Their installation called "Eloquent Robes" makes use of an individual's heart rate to project abstract representations of the measured heart rate on a garment. Through their installation, they found that users who intentionally tried to modify their heart rate had a stronger feeling of self-attachment towards the experience than those just observing with no bodily intervention.

The most relevant category of related. work focuses on shared and/or remote experiences based on the heart rate of individuals. For example, Walmink et al. [40] studied heart rate displays in a social context in which they displayed the heart rate of a bike rider on the back of cycling helmets. By this means, a group of bike riders have knowledge of the heart rate of others in the group which in turn enables a shared experience and supports engagement within the cycling activity. Werner et al. [42] built a system comprised of two rings capable of measuring the heart rate and sending the data to another corresponding ring. Both rings called "united-pulse" addresses couples who live at a distance and realize a remotely shared experience of the heart rate and creates an "*artificial corporeality*" between the couple wearing the rings. They found that minimal tangible output was sufficient to realize a sensual experience.

Another type of shared experience was demonstrated by Hoinkis et al. with "Herzfassen" [12]. They utilized a metal bowl filled with water to mediate the heart rate with artificially created waves on the water surface. They build a bass shaker into the bottom of the metal bowl which physically produced the different waves on the water surface. The authors noticed that people around an installation tend to play and create a "chain of arms" between the bowl handles creating a 'common' heartbeat as part of the shared experience.

The "Heart Sounds Bench" of Howell et al. [17] addresses the smart city context and aims to "*invite rest, reflection, and recognition of others' lives in public space*" which they describe as *life-affirmation*. They integrated a system that records heart sounds through two stethoscopes and speakers to play heart sounds into a red bench. Thereby, people are able to share their heart sounds with others sitting on the bench as well as getting aware of people previously sitting on the bench through their shared heart sounds. Here, the shared experience helps *recognizing others' lives, feeling connected, and embracing difference with opacity.*

Slovak et al. [38] addressed shared experiences with heart rate measures through a study in which they investigated how people understand their own heart rate and the heart rate of remote users within a so called physio-social space. They found two distinct categories of effects, that is the heart rate as information and the heart rate as a connection between users. Their work and their implications strongly encourage the use of heart rate communication to support social connectedness or other kinds of social interaction. Others have addressed how biosignal information can facilitate empathy and social awareness [11, 16, 25], including a sense of intimacy and connection [21, 24]. However, recently Liu et al. [26] argued that these related research often conflates the presence of information with their visual presentation. They demonstrated that presentation modality also matters; i.e., that visualization of heart rate has significant effect over textual presentation of biosignal information on interpersonal closeness with a stigmatized group member.

While the works discussed so far addresses shared experiences with heart rate interfaces in different social contexts, they explored only non-tangible sensations as heart rate feedback, e.g., visual [12, 38, 40, 42] or auditory [17]. In contrast to existing works, we include and focus on real-time tactile sensations created through the heart rate measures and compare the effects of receiving once own heart beats to receiving a partner's heart beats as stimuli.

2 PiHearts

We replicated and improved the design presented by Aslan et al. [1], including the application of a design process similar to what has been proposed by Loke and Robertson [28] and as in general proposed in design research (e.g., [43]). Ultimately, the process of exploring different techniques, materials, and forms, by building tangible heart displays helped us establish an expertise for this type of displays. Because we utilized a Raspberry Pi for the final tangible heart displays, we refer to them in the following as PiHearts.
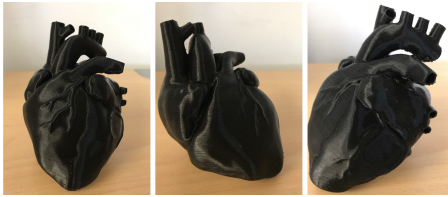

Figure 1: Improving the realism of the shape of the tangible heart design

2.0.1 Materiality and Form of a PiHeart. To form the heart display cover with silicon we replicated a method, which is often used to produce chocolate figures. First, we printed a realistic shaped heart (see Figure 1) and used its shape as template to produce a realistic looking and flexible silicon cover for the PiHearts (see Figure 1). One of the reasons why we went back to silicon from latex was a strong odor of latex, which was unpleasant. Ultimately, we used a pouring technique to put the silicon inside the heart shape, which allowed us to create a heart cover that was flexible, and was shaped like a real heart including the veins on its surface. We had to be careful to choose a very flexible silicon type, which would stay flexible over time. We chose to use a non-skin color for the silicon, which we believe made the PiHearts appear more aesthetic and playful, and less medical and clinical.

2.1 Hardware

We crafted two prototypes, whereby a PiHeart prototype consists of two components: a mobile main unit and an output unit. The main unit contains a Raspberry Pi Zero W, all required sensors, and the power supply for all components. The output unit includes an Arduino micro-controller that controls two RGB-LEDs and a servomotor. Both units are connected with each other by a plug connection. Figure 3 outlines the connections between all components of the prototype. Figure 5 shows on the left side a pair of a main unit and an output unit together with their 3D-printed housings and the servomotor enclosed in the silicone heart. The main unit and the heart rate sensor can be attached to an arm, respectively
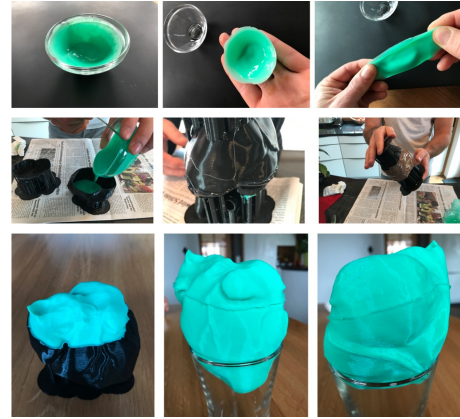

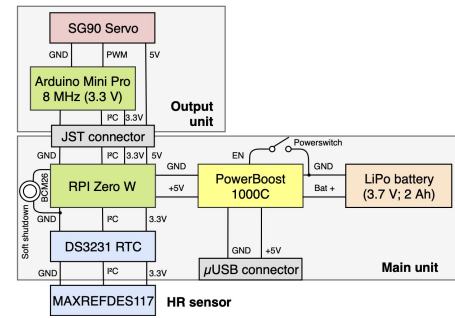**Figure 2: Process of making the PiHeart silicone cover.**

Figure 3: Device connections of the two pairs of main and output units.

finger tip, by means of Velcro strips. Figure 4 allows a view of the electronics of the main and output unit.

Main unit. The main unit contains a LiPo rechargeable battery with a capacity of 2 Ah connected to an Adafruit PowerBoost 1000C[1] circuit. This circuit contains a TPS61090 boost converter and is able to charge the battery via USB while in use. The circuit delivers a voltage of 5 V with a maximum current of 2 A. The power supply to the main unit can be switched on and off with a switch. The theoretical maximum current consumption of the main and output unit (1A) allows in our configuration with the capacity of the integrated LiPo battery a runtime of 2 hours.

All other components are connected to the Raspberry Pi Zero W and are partially powered by its 3.3 V voltage regulator. The Raspberry Pi collects all sensor data and controls all other devices.

One of the two main units includes additional sensors that are included for future research. Both main units include a DS3231 real time clock (RTC) and a MAXREFDES117[2] circuit with an optical MAX30102 heart rate sensor. We attached a Velcro strip to the sensor breakout board and protected its circuits with a silicon

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[1]https://learn.adafruit.com/adafruit-powerboost-1000c-load-share-usb-charge-boost/overview (accessed July 10, 2019)

[2]https://www.maximintegrated.com/en/design/reference-design-center/system-board/6300.html (accessed July 10, 2019)
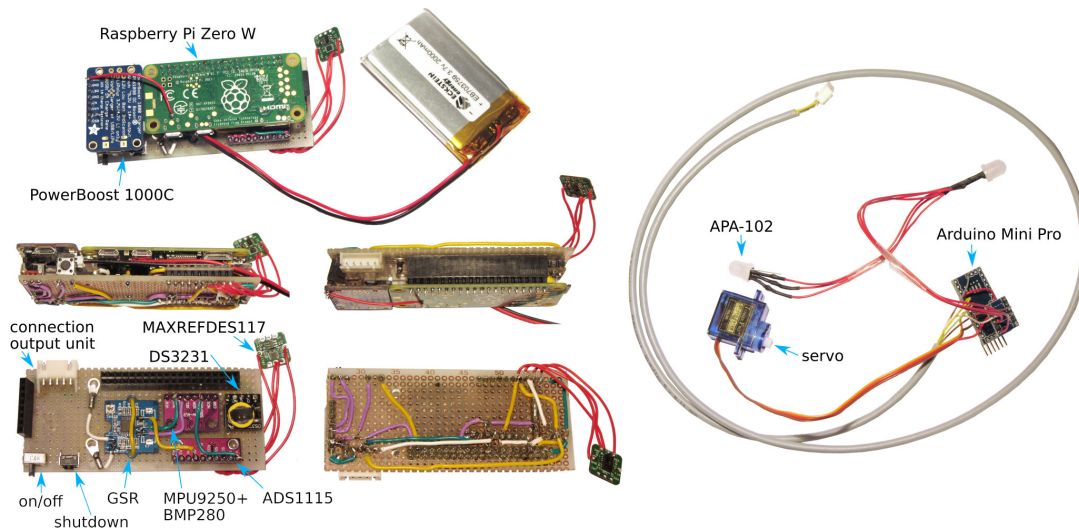
Figure 4: On the left several views of the partly disassembled main unit are visible. The heart rate sensor didn't include the circuit protection and Velcro strip yet. On the right the electronics of the output unit are shown.
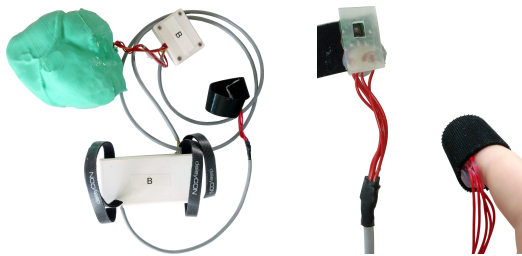

Figure 5: One complete PiHeart prototype including both units enclosed in 3d printed cases and the servomotor inside the silicon heart is shown on the left. On the right the heart rate sensor with Velcro and silicon protection is visible in detail.

plate with a hole for the optical sensor part. The Velcro strip was responsible to fix the sensor with the finger tip. Figure 5 (rightmost item) depicts the sensor in detail.

Output unit. The output unit can optionally be connected with a JST plug connection to the main unit. It is possible to connect several other sensor or actuator devices that can communicate with the main unit via the I2C interface. In this case the output unit consists of an Arduino Mini Pro with a clock of 8 Mhz powered by the 3.3 V voltage, an SG90 servomotor and two APA-102 RGB-LEDs which are connected to the Arduino via a levelshifter. One of the two output units does not provide the two RGB-LEDs. The Arduino acts as I2C slave which receives and executes external commands, in this case from the Raspberry Pi. The servomotor is directly connected to the 5 V voltage since it draws more power. The required PWM signal can be provided with a voltage of 3.3 V by the Arduino. For the RGB-LEDs which are also driven with

5 V the 3.3 V signals of the Arduino can cause problems so that a levelshifter is used.

2.2 Software

An overview of the communication between the software components is sketched in Figure 6. In the following, we describe the software of each of the devices.
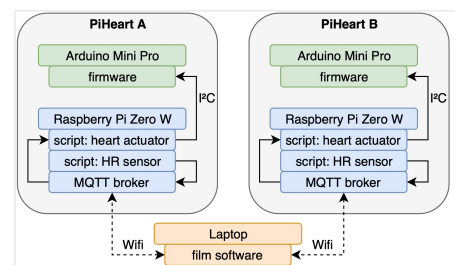
Figure 6: The communication between the devices and the programs.

Arduino. For the Arduino, we developed a firmware that allows to use it as I2C slave via the I2C bus of the Raspberry. Two libraries for the control of the servomotor and RGB LEDs are used. Only one command is implemented which can be sent from the Raspberry. Whenever it is received by the Arduino, a heart beat is conducted. In this case, the axis of the servomotor is set from position zero to 180 and back again while running at full speed.

Raspberry Pi.
On the Raspberry, Raspbian Linux was running. It was configured to automatically connect to a specific WiFi-network. Two scripts were developed in Python 3 and communicate with other programs

on the network via MQTT protocol. On each Raspberry, a local instance of the MQTT broker mosquitto is running. The first script controls the output unit by sending at a specific interval (heart rate) the command to conduct a heart beat to the Arduino via I2C. The heart rate is controlled via MQTT messages. The second script is more complex. It acquires and calculates the current heart rate of a user from the BVP (blood volume pulse) signal in real time.

After the acquisition of the BVP data, the heart rate has to be calculated with the relatively slow single core Raspberry Pi Zero W. In general there are two possibilities. It is possible to calculate the time differences between two peaks which have to be found or a FFT is conducted where the frequency with the highest magnitude is the heart rate.

We used the FFT approach which required less CPU performance. The MAX30102 was set to provide BVP data at a sample rate of 100 Hz. The window size of the STFT was set to 30 seconds (3000 samples) with an overlap of 75 % (2250 samples) to be able to calculate the heart rate every 7.5 seconds. The samples of a window were normalized by their maximum value before applying the FFT. It provides a frequency resolution of 0.033 Hz which are about 2.0 bpm. For the calculation of the heart rate just frequencies in the range of 40 to 300 bpm were considered so that some (movement) artifacts are filtered out. From this range the frequency with the highest absolute value of the real part of the complex numbers is output and provided as MQTT message. The raw BVP signal is additionally sent. The results of this algorithm showed comparable values to a consumer blood pressure meter so that it provided a high enough accuracy for our purposes while providing an easy sensor setup.

Laptop. A software written in C# was running on a Windows laptop that controls both PiHeart prototypes, records data and shows the movies. In an SQLite database following data is stored with timestamps: heart rate, the shown movie title, the modality and the raw BVP data. The timestamps created by the laptop software are used for data synchronization as the latencies from data transmission and Wifi connection are usually not very high. In the beginning of each study session the software starts on both Raspberry Pis via SSH connection the two required scripts. The software connects to both MQTT brokers on the Raspberry Pis so that it can communicate with both of them. Since no central MQTT broker is used the laptop can easily be replaced with another device without having to adapt the scripts on the Raspberries. Sending data via network broadcasts was not reliable as some Wifi routers block them.

3 FIELD STUDY

To research how the usage of the PiHearts would influence users' experiences in an everyday social setting we decided to conduct a field study with pairs of participants. Since watching movies is a paradigmatic shared everyday experience, we decided to ask the pairs of participants to watch movies together while using the PiHearts.

We were specifically interested in exploring how the heart displays could potentially change participants' experience by either displaying their heart beats to themselves or to their "co-viewers". Thus, the field study aimed at exploring the following research question: *How do the usage of PiHearts potentially change users' experience during a shared movie watching activity when the heart*

Figure 7: Participants and setup of the field study.

displays feed back (i) users' own heart beats and (ii) when they feed back their "co-viewers" heart beats?

Our expectations and believes prior to the study were focussed on experiences associated with how they related to their surrounding world (e.g., immersion and empathy). We believed that by feeding back users their own heart beats with the PiHearts we might be able to strengthen their "relationship to their bodies", and thus, increase their mindfulness (e.g., ability to immerse in the moment). We assumed feeding back users their "co-viewers"' heart beats might in addition increase social awareness (e.g., empathy). Ultimately, we hoped that the PiHearts would in both conditions improve participants' experiences and potentially foster experiences of resonance (e.g., "become one with the environment" through immersion and empathy) and not the opposite (i.e., alienation).

3.1 Participants and Apparatus

We recruited 60 participants (30f, 30m) from our own circle of acquaintances for the field study of which 24 reported to be couples in a (romantic) relationship, 4 reported to be friends, and 2 reported to be family members (i.e., sisters or brothers). Participants' ages were divers with, for example 14 participants reporting to be between 45 and 65, and 17 between 18 and 24. The PiHearts, including the laptop, which we described in the previous section were utilized for the field study. Considering the selection movies, we chose the three movies "big bunny", "overwatch", and "for the birds". Considering the choice of movies, we went through multiple rounds of discussions. We aimed to choose very similar movies with similar ratings on sites, such as www.imdb.com. We tried to choose movies, that are emotional but international. We ended up choosing the animation movies with no language and sound effects only. Overall, our main interest was in how the heart display usage modality would influence users' experiences, which we controlled by counter balancing the order of modalities and choosing similar movies. Nevertheless, fellow researchers should be aware that the absolute UX ratings we report in results are influenced by the choice of movies.

3.2 Procedure

First we conducted a pilot study with two (separate) participants to make sure that our study setup had no major flaws. Afterwards we conducted the study with the 30 pairs of participants within four subsequent weeks. Figure 7 depicts exemplary participants and contexts of the field study. There were three conditions which we studied. The study was a within-subject study. Consequently, we collected data using a user experience questionnaire from each pair of subject for each condition. Conditions were watching a movie without any heart beat feedback, watching a movie while holding PiHeart in their hands while PiHeart displayed each participant's own heart beat, and watching a movie while holding PiHeart in their hands and PiHeart displayed their partners heart beats. The order of the conditions was counter balanced while the order of the movies was fix. For the field study we decided to choose the three different movies and not one, since we were interested in user experiences, and clearly, watching the same movie a second or third time would strongly influence participants' experience. At the end of the study we conducted a semi-structured asking questions such as "Please describe the feeling of holding your own heart beats" and "Please describe the feeling of holding the heart beats of the person beside you".

In order to measure relevant user experiences we decided to utilize the game experience questionnaire [19] because this questionnaire measures constructs, such as "Sensory and Imaginative Immersion", "Positive Affect", "Negative Affect", "Flow", which are all relevant in terms of how someone experiences the surrounding world. Moreover, the game experience questionnaire has a social presence module, which measures "Negative Feelings", "Empathy", and "Behavioral Involvement" with all being relevant to a social setting and potentially the notion of social resonance. The game experience questionnaire was applied after each movie. The analysis of the responses to the open ended questions which were asked at the end (i.e., after participants had watched each movie and reported filled out the user experience questionnaire) was performed by a thematic analysis [5] in which we identified topics/themes relevant to our research question and sorted the topics/themes in participants' answers by frequency.

3.3 Results

Figure 8 and 9 present the results of the UX questionnaire. Figure 8 depicts participants' ratings considering their "in-movie" experience and the Figure 9 depicts participants' feelings considering social presence.

Table 1 presents results of a repeated measurement ANOVA and in case of a significant result consequent post-hoc pairwise comparisons (with Bonferroni corrections) for each measured UX construct. We found a main effect of modality on "Sensory and Imaginative Immersion". Pairwise comparisons show that there is a significant difference between the modalities "WithOwnHeart" and "WithoutHeart", meaning that participant felt significantly higher levels of immersion when they held the PiHeart with their own heart beats being displayed compared to the condition when they didn't have a PiHeart in their hands. Considering the social presence module, we found a main effect on all three constructs (i.e, "Empathy", "Behavioral Involvement", and "Negative Feelings")
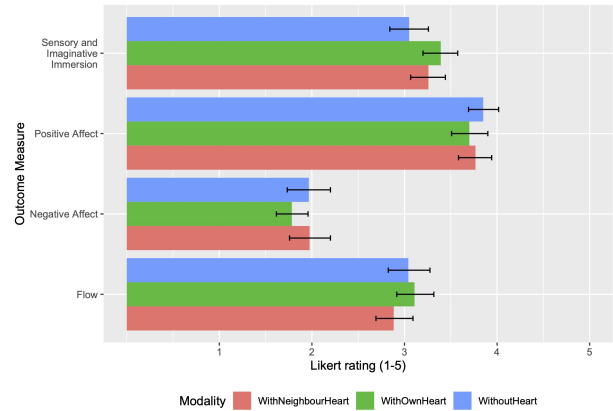

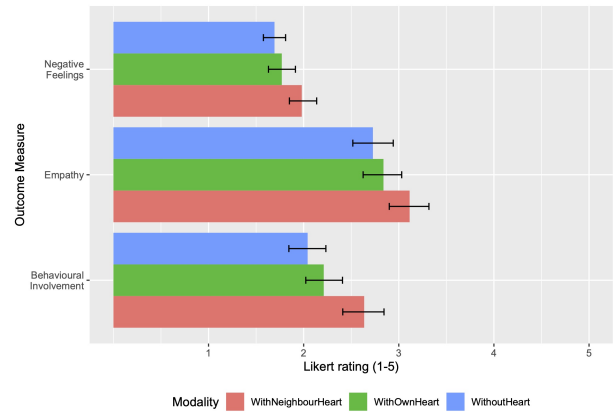**Figure 8: Results of the UX questionnaire**

Figure 9: Results of the social presence module

with post-hoc pairwise comparisons showing that there are significant differences between the condition when participants used the PiHeart with the neighbors'/partners' heart beats being displayed compared to the other two conditions. When participants watched the movies while holding their neighbors'/partners' heartbeats in their hands, they felt significantly higher levels of social presence.

3.4 Analysis of the semistructured interviews

In the semi-structured interviews, which we conducted at the end of each study session we asked participants a couple of additional questions including the open ended questions of what they liked best and what they liked least. Most participants (#17) stated that they liked best the fact that they could feel the heart beats and that the heart rate was not presented in numbers/letters. Followed by 14 participants stating "feeling the other person's heart beat". Three participants explicitly mentioned "increase of self-awareness considering their heart rate".

When we asked participants about what they liked least, most of the participants mentioned one of the movies. Two participants

Dependent variable	F-value	p-value	Post hoc pairwise comparisons (Bonferroni)
Positive Affect	F=1.40	p=0.25	
Negative Affect	F=1.69	p=.19	
Sensory Immersion	F=4.78	**p=.01 ***	W-N (p=.32); O-N (p=.63); **O-W (p=.003)**
Flow	F=2.06	p=.13	
Empathy	F=8.55	**p<.001 *** **	**W-N (p<.001 ***); O-N (p=.02 *)**; O-W (p=.92)
Behavioral Involvement	F=16.71	**p<.001 *** **	**W-N (p<.001 ***); O-N (p=.0015 **)**; O-W (p=.29)
Negative Feelings	F=7.53	**p<.001 *** **	**W-N (p<.001 ***); O-N (p=.03 *)**; O-W (p=.96)

Table 1: Overview of the statistical tests over all participants, including the overall effect of *modality* on measures for experience and social presence; and pairwise comparison based on post hoc tests (Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1). (Abbreviations used for reporting pairwise comparison: WithoutHeart-WithOwnHeart (W-O), WithoutHeart-WithNeighborHeart (W-N), and WithOwnHeart-WithNeighborHeart (O-N))

explicitly stated that they least liked being distracted by the heart display.

The issue that was stated most by participants (#13) as a potential issue with the usage of a heart display was that one started to get nervous once one felt that the heart beat was rising. When we asked participants what potentials they saw with a tangible heart display the most provided answer (#12) of participants was related to health and improvement of body consciences followed by couple therapy (#7).

When we asked participants about what they felt when they held their own heart beat the most stated answers were "it was interesting to feel changes" and that "it felt faster than what they would have expected". Interestingly the answer that was provided most by participants when we asked them about what they felt when they held their "partners" heart beats they said something like "one feels in competition with each other trying to have the lower heart rate", which explains why there has been a significant result considering the "negative feelings" (often associated with competitive feelings) construct, which is part of the social presence module/questionnaire.

4 DISCUSSION

Hartmut Rosa [34] has argued that because of social acceleration people seem to desire moments of resonance, which they search for in mindfulness apps and doing practices such as yoga, digital detox, etc. Unfortunately, he does not provide specifics about how one can design or measure resonance. But it seems that exposing people to natural stimuli can help [9] and isn't a heart beat a natural stimuli? However, most of our technology-enabled interactions are only screen based. For about two decades Hiroshi Ishii [20] has criticized the experiential qualities of such screen-based human-computer interfaces as unfortunate and that: *"one can not feel and confirm the virtual existence of digital information through one's hand and body"*. He argued that tangible interface designs will allow us, as humans to experience digital information (with our bodies) in richer ways.

In our own past work, like many others in our community, we also focussed on multimodality to improve performance, for example in way finding [2] and to assist in communication between different cultures and languages [3]. Today, we are more aware than ever that modalities and related expressivity can also enable

wellbeing. With PiHearts we provided an example design that provides a user's heart beat as a natural stimuli in real-time. Overall, the study results support our stance to consider the human body as living and multi modally sentient, with the abilities of implicitly communicate and relate to its surrounding world. In this stance, the human body can act as a living active antenna capable (and maybe even driven) to establish resonance with the surrounding world. In the following we discuss various results and observations in a structured manner.

4.1 Experiencing oneself

We found that when the PiHearts displayed participants own heart beats they reported significantly higher levels of immersion than when their experience was not augmented with heartbeats. In general, high levels of immersion is arguable a result of being in strong relation to things or persons that one is engaging with. The utilized questionnaire measures immersion by measuring interest in the movie story and impressiveness of the experience. Consequently, participants reported to be more "interested in the movie's story" and reported feeling more impressed when they watched a movie while holding the PiHeart which displayed their own heart beats in their hands.

4.1.1 Simulated resonance with oneself. It seems as if integrating one's heart beat into the (movie watching) experience caused participants to experience significantly higher levels of immersion and maybe feeling less lost in other distant thoughts and chaos. Our results could mean that there is a chance that feeding back one's heart beat "simulates social resonance" and thus reinforces immersion. Put differently, experiencing once rhythmic heartbeat through a tangible display seems to set a person in a state of immersion, and maybe resonance and harmony, because one's real heart beat is in synchrony with what is being displayed. Bennet et al. [4] have utilized the idea of resonance to explore harmonic interaction with virtual pendulums making use of subliminal micro-movements. Future work is needed to study the potential of heart beats as design material to serve a similar purpose of harmony and stabilization. Based on our study results, we are hopeful that this is possible in other contexts and designs, and rhythmic patterns of oneself if fed/looped back to users, will similar to the notion of an

affective loop (e.g., [13, 15]) reinforce immersion and may support experiences of (social) resonance and harmony.

4.1.2 Somaesthetics. It is not unusual for the inner workings of the human body to be hidden from conscious awareness, allowing users to perform tasks in a more efficient and automated, but often mindless and self unaware manner. Our work is partially motivated by Somaesthetics (e.g., [37]), a "theory" and interdisciplinary field that among other things proposes to improve self-awareness through somatic introspection (e.g., body scan exercises). With the term soma an emphasis is put on the living body, which is becoming increasingly important as tool in the design process [14] itself, and fellow researchers are increasingly applying soma-based design as a method to design and inspired critique (e.g., [8, 23, 39]).

Shusterman advocates improved self-awareness, including sensitivity towards difficult to perceive behaviors, such as one's heart's beating patterns, which are always there but tend to be in the background of a person's awareness. Representations about oneself have a fascinating pull and effect, possibly because most of our senses (as argued by Shusterman) are directed towards the outside and rarely we sense/meet our selves with the exception of using mirrors or viewing media containing representations of our selves, such as selfies. Heart displays can undoubtedly, bring the inner workings of our bodies to the foreground for introspection, without requiring any training or skill, and the tangible nature of displays may increase the experiential qualities. Ultimately, one may have it easier to become aware of one's behavior and potentially regulate the behavior, and be able to this even in an everyday situation, such as watching a movie.

4.2 Experiencing the other

Results of the field study have also shown a significant effect on social presence when participants' PiHearts displayed their partners' heart beats. We found significant results for all three constructs measured by the presence module. Participants reported significantly higher levels of (i) empathy (e.g., connection to their partners), (ii) negative feelings (e.g., feelings associated with being in a competition), and (iii) behavioral involvement (e.g., believing that they adapted to each other's heart beats).

4.2.1 Experiences of resonance and alienation. Negative feelings were measured by questions associated with feelings of jealousy or "schadenfreude" (malicious delight), or revengefulness. All these feelings seem associated with participants being competitive. In the interviews, participants mentioned that they wanted their own hearts to beat slower than their partners. Empathy is measured by questions associated with feeling connected with the other, feeling happy when the other is happy, or finding it enjoyable to be with the other. Empathy and negative feelings are both sub-constructs of psychological involvement. Ultimately, both (different kinds) feelings were significantly influenced. Dynamics and variation in the relationship between the pairs of users could be one explanation. Another explanation could be that the tangible display reinforced feelings of both, resonance and alienation. Feeling the other person's heartbeat could have provided at times feelings of alienation, when the heart beat pattern of the other was not similar to one-selves. We have experienced that when people experience a

tangible heart display, it may cause some irritation (or alienation) in the beginning, because the thing seems "alive". There could be an undesired "uncanny valley" effect, which is a phenomenon well known in human-robot interactions, which we did not explore but which may foster feelings of alienation. But, of course such "bodily background modalities" could in future enrich adaptive multimodal human-robot interactions and affective expressions (e.g., [32, 33, 41]). Future work is needed to uncover details. Until then, it is important that devices, such as the PiHeart need to be used with care because there is potential foster undesired alienation.

Participants also reported significantly higher levels for behavioral involvement when experiencing the other person's heart beats. Behavioral involvement is measured by statements, such as that one's actions depended on the other person's actions, and that what one did affected the other. Essentially, behavioral involvement is about agency and effectiveness in a reciprocal interaction setting. Hartmut Rosa argues that digitalization is increasing our effectiveness, which is an important aspect for feeling resonance, but digitalization can also increase feelings of ineffectiveness (e.g., when a mobile's battery is down).

4.2.2 Social Somaesthetics. The human body, or soma, is not only a living tool, which has the potential to provide rich self-directed experiences, such as taste and smell. It is a "face" that we utilize in social interaction. We perform self-styling, self-fashioning, self-presentation to be perceived as young, cool, beautiful, strong, intelligent, educated, etc. The social setting and the habit of self-presenting may have been a cause for negative feelings. In the user study, one could argue that the participants tried to self-present themselves by trying to have a slow heart beat, which would be associated with being calm, in control, and healthy. One could also argue that we asked participants to perform a somaesthetic practice directed towards someone else, such as a masseur providing a massage, which is a category of practices [37].

4.3 Conclusion

In this paper we reported on research in designing and evaluating embodied heart displays, which enable the perception of a person's heart beats as natural stimuli. We presented technical details of the heart displays to allow replicability of the design. We also discussed in detail the results of a field study with 30 pairs of participants evaluating the effects of using the displays during a mundane shared everyday experience (i.e., watching movies together). We found, for example, that participants report significantly higher levels of imaginative and sensory immersion when the tangible heart displays display user's own heart beats; and participants report significantly higher levels for behavioral involvement when the tangible heart displays display the other person's heart beats. We have both motivated our research and theoretically grounded it by referring to (i) Somaesthetics as an increasingly interdisciplinary field, which addresses the various uses of the human body and (ii) resonance theory as a modern theory to explain and discuss the effects of using tangible heart displays on social user experiences. We hope that our research will inspire fellow researchers to explore how physiological (and rhythmic) data can serve as an additional modality and natural stimuli to enrich future multimodal interactions.

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