Touchless touch with biosignal transfer for online communication

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ABSTRACT

The widespread of audio-visual online communication highlights the importance of enhancing their ability to transmit emotional color and personal experience. Non-verbal biometric cues and signals were recently recognized to convey such missing emotional context when added to virtual interactions. Motivated by that, we present a haptic system allowing for a biometric signal transfer in a fully touchless and seamless way. We utilize camera-based heart-rate signal readings and ultrasonic mid-air haptic technology to affect the audience with a temporal tactile pattern representing the speaker's heart rate. We assess the usability and engagement enhancement of such a system in two user-studies involving one-way communication, i.e., watching a short emotional video. Our analysis of biometric data and subjective responses hints toward changed values of arousal and valence as well as physiological responses when the haptic feedback was applied in a group of participants. Finally, we outline a further research agenda to confirm our observations with different emotions and communication scenarios.

CCS CONCEPTS

• **Human-centered computing → Human interaction (HCI); Empirical studies in collaborative and social computing**.

KEYWORDS

biosignal transfer; haptics; gaze detection; communication; experience

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1 INTRODUCTION

In expressive communications, our words and body-language are coupled to changes in our psychological state. Our heart rate goes up when we feel anxious or uneasy. Our skin conductance and eye pupil size increases when we are aroused [49]. On the receiving end, the audience's psychological state also changes, often reacting to or mirroring that of the source. Meanwhile, most digital communication platforms (e.g., audio and video calls) limit our capacity to express ourselves, thus reducing our ability to convey the peculiarities of emotional color and personal experiences. As the world communicates increasingly using such online platforms (e.g., for remote work, video chat, metaverse, etc.) enhancing the emotional component of our audio-visual conversations through the haptic channel becomes evermore timely and relevant.

Biosensing and biofeedback have been used extensively to improve health [21] and performance arts [7]. Increasingly however, these are also used to enhance online communications and social interactions. For example, subtle non-verbal cues such as respiration patterns, sweating or heart-rate biosignals which we are naturally capable of directly observing and interpreting in our everyday face-to-face experiences, can also be shared online via some proxy, e.g., during a video call to enhance empathy, the sense of co-presence and intimacy as detailed in this recent review article [16].

Conventional audio-visual and text channels allow for a number of ways to transfer biosignals via soundscapes, direct memos or visual effects and shapes [13, 25, 35, 43]. However, as the latter can also lead to a distraction from the actual context of communication, haptic interfaces have been proposed to serve as an alternative medium to transfer biosignals exhibiting temporal variability [9]. To that end, a number studies have explored the use of contact haptic interfaces (wearable or tangible objects) to communicate emotional affect, social touch, or biosignal transfer [15, 16, 27], however very little has been done using non-contact haptic interfaces such as ultrasound mid-air haptics [2, 8, 42].

Ultrasonic mid-air haptics (UMAH) is an emerging technology that uses ultrasound speakers to induce a vibrotactile sensation on the user's skin from afar; no controllers or wearables needed (see recent review [44]). The majority of the literature has leveraged this technology to provide haptic feedback to the user's palms and fingertips as tactile confirmation to some hand gesture input during system interaction, while few papers have targeted other parts of the body such as the face [23] and arms [20]. UMAH is completely non-intrusive and hygienic, UMAHs have a large haptic sensation space that we can explore going forwards. UMAHs apply a variety of spatiotemporal haptic patterns, which could be linked to different emotions. The advantage of using mid-air haptic technology to enhance expressive communications is potentially two-fold. Firstly, it does not require the use of wearables, haptic surfaces, or contact controllers, therefore enabling touchless (i.e., contactless, or tethereless) interactions between a communication pair (one-to-one) or group (one-to-many). Secondly, past literature has demonstrated the ability of this technology to mediate a variety of emotions (e.g., happy, sad, excited, afraid) [42].

This paper presents a one-way (asymmetric) multisensory (audio-visual-haptic) touchless communication system; a first step towards our vision of enhanced two-way (symmetric) multisensory communications. We thus report on a series of studies that compare physiological changes due to an emotional audio-visual (Case 1) and an audio-visual-haptic (Case 2) communication instance, i.e., when watching an emotional video message. Importantly, we chose to use two short videos taken from YouTube, therefore casting a wider net but also introducing several uncontrolled factors. Two user studies were then performed during which we measured Heart Rate (HR), Respiration Rate (RR), galvanic skin response (GSR), eye gaze and pupil dilation (PD) using a collection of appropriate measurement sensors. A variety of subjective questionnaires were also completed by our participants, namely, the Positive and Negative Affect Scale (PANAS) [50], the Social Touch Questionnaire (STQ) [26], and the Self Assessment Manikin (SAM) [4]. Our findings suggest that the shared information of the speaker's biosignals via mid-air haptic technology can affect the emotional engagement of the audience during multisensory virtual communication.

We first present the current state-of-the-art and related works (see Sec. 2), then provide a description of our experimental set-up and methods used (see Sec. 3). Details about the two user studies are then described (see Secs. 3.3 and 3.4) followed by their respective results and findings (see Sec. 4). Finally, we focus on the limitations and conclusion of performed experiments (see Sec. 5).

2 RELATED WORK

Embedding physiological responses into human-computer interaction (HCI) systems to perceive and modulate the emotional state of a subject has long been a topic of active research within the affective computing domain [2, 51]. With affective communication being an important part of the above paradigm, most studies have focused mainly on communicating perceived and interpreted emotional states. In fact, the direct sharing of non-interpreted biometric data in the context of experience communication emerged as a fairly recent topic [16]. While not directly interpreted, this additional deeply personal information has a potential to enhance the quality of remote and online communications. Namely, the displaying of ones heart-rate can result in increased trust, higher levels of engagement or dependability [29, 39]. To that end, a number of studies have explored biosignal sharing via a variety of channels and devices like smartphones (videochats [25]), smartwatches (avatars [36, 43]), computer screens (games [34]), virtual and augmented reality goggles [34], audio [52], and haptic feedback (ambient display, [41], pedant [19], teddy bears [51], clothes [40], mid-air haptics [46]).

Commonly observed and shared biosignals include heart-rate (HR), respiration rate (RR), skin conductance as measured through galvanic skin response (GSR) sensors or an Electrodermal activity (EDA) meter, body temperature and brain activity obtained through an electroencephalogram (EEG). Sharing heart-rate biosignals can increase the perceived level of intimacy stimulating closeness, increasing higher communication engagement and understanding, and could prevent social stress [11, 14, 18, 22, 29]. This is related to a link between stress response and emotional arousal to increase in heart rate frequency and its variability [24]. Skin conductance (GSR) or Electrodermal Activity (EDA) is well known as a sensitive marker of emotion-related autonomic arousal [31]. It also provides quantitative data for the examination of emotion changes [10].

Haptic technologies are well known to allow for modulating and generating rich emotional responses. Rantala et al. [45] argue that affective haptics can dynamically reinforce (intensify) our feelings or reproduce (simulate) the emotions felt by someone else. The papers by Frey et al. [19] and Lee et al. [33] show how sharing personalised biofeedback and tactile sensations impact emotion recognition, creating intimacy and communication involvement. Chen et al. [9] explore the design space for multi-sensory heart rate feedback in immersive virtual reality, while Dey et al. [11] study the effects of sharing real-time multi-sensory heart rate feedback in immersive collaborative environments Kim and Schneider [32] describe how different types of tactile settings influence user experience (UX), while MacLean et al. [37] what makes multisensory haptic interaction design so challenging. Finally, and perhaps the most relevant works to our study, the papers of Ablart et al. [1, 2], Obrist et al. [42], and Romanus et al. [46] use ultrasonic mid-air haptic technology to increase immersion, transfer and modulate emotions thus contributing to the overall experience quality.

3 MATERIALS AND METHODS

We are interested in asymmetric (one-way) communications, where there is a distinct source (speaker) and receiver (audience) pair. Further, these two roles are not reversible and there is no feedback in the communication between them.

3.1 Elicitation video description

In our setup, this translates to participants watching short videos of prerecorded actors, narrating a short emotional story. Two 3-minute YouTube videos were selected for this purpose, each containing male actors that share their sad story [28, 47]. In the first video, the actor portrays a father transmitting an endearing farewell message to his dying son. In the second video, a different actor shares his story of loosing his son to the ongoing Palestine-Israel conflict. These emotional videos were chosen to elicit psychophysiological activation, enhance sense of belonging, and to empower the effect of social explicitly [17]. We note that while the main theme of the two emotional videos is similar (both sad stories about personal loss), the delivery and talking points are very different, therefore introducing uncontrolled uncertainties in our study however enabling a more real-world test case.

3.2 Touchless biosignal communication setup

During this one-directional experience the communication channel is enhanced with a mid-air haptic sensations (in Case 2 only) at the receiver end, and we are interested in understanding if that induces any additional physiological changes. To that end, we have performed two user studies and two conditions (Case 1 and Case 2) as outlined in Figures 1 and 2. The first user study (pilot) was a between-subjects study design where a total of 20 participants tested the two conditions. Ten participants experienced Case 1, and the other ten experienced Case 2. The study procedure followed four stages and lasted about 30 minutes from start to finish. All participants watched the same pre-recorded movie (Movie 1), but only half of them experienced Case 2 (movie with haptics). During the study, participants completed the subjective PANAS questionnaire and we recorded objective HR and GSR data using a collection of sensors. Further details and results from user study 1 are provided and discussed below.

Following the analysis of the results from user study 1, we designed a refined user study 2 where we would collect more data, from more participants. Also, we introduced a second emotional movie clip (Movie 2) thus enabling each participant to experience both conditions, i.e., a within-subjects study. A total of 36 participants went through the 7 stages of the second user study protocol during which they completed several subjective questionnaires (PANAS, SAM, and STQ), and we recorded several objective data streams (HR, RR, GSR, PD, Gaze) using additional sensors. The study procedure lasted about 60 minutes from start to finish, and required each participant to watch two different movies, one with haptics (Case 2) and one without (Case 1). The experiences, movies and cases were randomised and counterbalanced among the participants. Further details and results from user study 2 are provided and discussed below.

3.3 User Study 1 (Pilot)

3.3.1 Participants. We recruited 20 volunteers (mean age 20.2 ± 0.68, 10 females, 10 males) as we wanted our data to have a balanced sex-ratio. Users reported that they were not under the influence of any antidepressants or other drugs affecting their mental state in the last year, and they had no impairments to their sense with touch and had no stressful or particularly significant day. A group of 10 people (5 females and 5 males) underwent the experiment with Case 1, and analogously 10 people (5 females and 5 males) experienced Case 2.

3.3.2 Study Protocol. The experimental procedure consisted of 4 stages and was reviewed by the local bio-ethical committee. National Covid-19 restrictions and safety protocols were followed throughout the study.

Stage 1 Welcoming of the participant and Questionnaire. Participants were presented with a consent form with information about the study and their data privacy. We then performed a heuristic analysis, in which we asked if the participant faced any stressful or extraordinary situation, which could influence the behaviour during the experiment. We excluded participants with psychiatric disorders and under strong stress on the experiment day. Each of the participants filled the PANAS questionnaire about their emotional state before the experiment.

Stage 2 (only for Case 2) Mid-air haptics familiarisation phase. Participants were asked to conveniently place their hand freely on a special tripod over the haptic device resulting in a constant distance of 30 cm from it. The distance was chosen subjectively to maximize the perception of the haptic feedback.

Stage 3 Experience and objective data collection. Participants were seated comfortably in front of the screen, fitted with the GSR sensor, and were provided studio headphones. In Case 2 they also experienced a dynamic mid-air haptic pattern modulated by actor's HR. For both cases, we measured participants biosignals during the experiment (HR and GSR). We divided each of the signals' representation into two groups – a *baseline* that reports the first 45 seconds of the experimental conditions, and the remaining 2 minutes of the signals were considered as the *experiment data*.

Stage 4. Questionnaire and Debrief. Just after the experiment, participants had to fill the PANAS questionnaire again to unveil any changes in their emotional state. We also had a debriefing talk to discuss what participants understood from the movie, if their feelings changed after watching it. If so, what could have changed their mood, what stimuli were the most significant for them in the context of the interaction.

3.3.3 Study Setup. During Stage 3 of the study protocol, participants were seated comfortably in front of a screen, fitted with the GSR sensor on their right hand, and were provided studio headphones to isolate ambient and device noises, while also being able to listen to the video playback sound as shown in Figure 3. During Case 2, in addition to the usual audio-visual communication channels available during video playback (screen and headphones), the seated participant also experiences tactile feedback. The tactile feedback was generated by an Ultraleap STRATOS Explore (USX) device composed of a 16x16 ultrasonic transducers array which was enclosed inside an open top-box, on which the users could comfortably position their left palm on so as to receive the mid-air vibrotactile sensation.

3.3.4 Case 2: Haptic biosignal transfer. The haptic pattern presented to the participant's palm during Case 2 was a circle with a dynamically changing radius oscillating between 2 and 5 cm, following a square waveform (Figure 4c)), similar to that used in [46], as shown in Figure 4. The frequency with which the circular haptic pattern oscillates (or beats) was related to the HR biosignal of the actor in the video. The actor's HR was extracted from the video using the Bisosense SDK [3] that observes slight skin color changes and motion in the video feed, a technique also referred to as remote photoplethysmography (rPPG). The actor's HR was then quantized (see Figure 4b)) and used to set the beating frequency of the haptic circle pattern: Actor HR below 60 BPM were haptically presented to the participant's palm at 60 BPM by the USX device. The 60-80 BPM range was presented at 80 BPM, and the 80-100 BPM range was presented at 100 BPM. Actor heart-rates above 100 BPM were

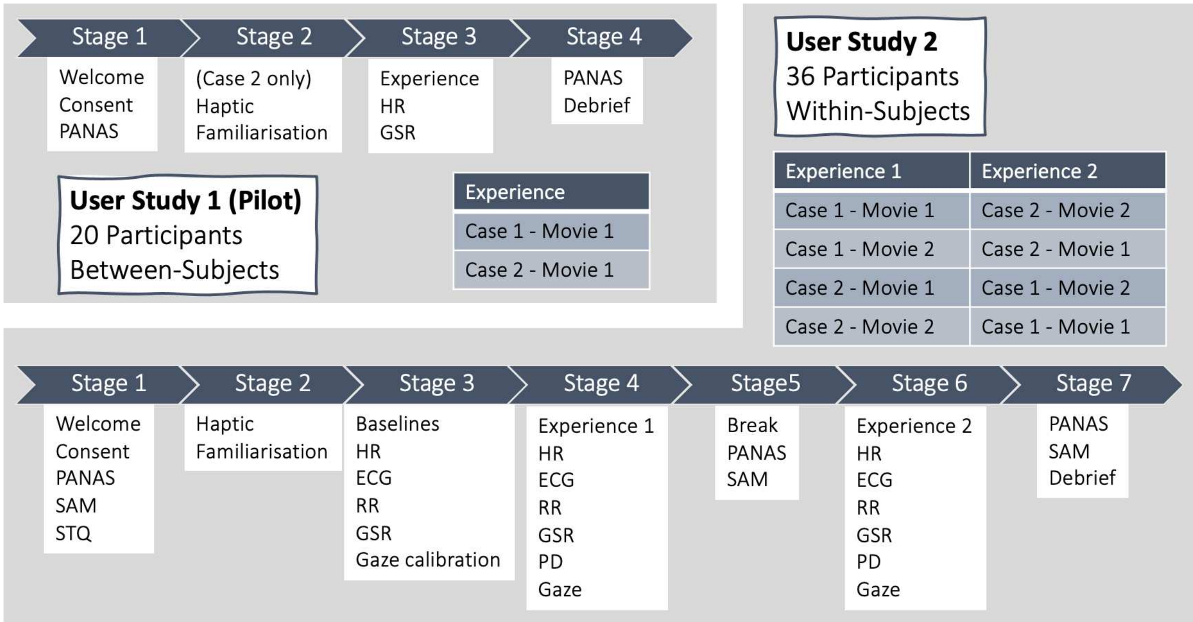

Figure 1: Study design protocols for User Study 1 and User Study 2.

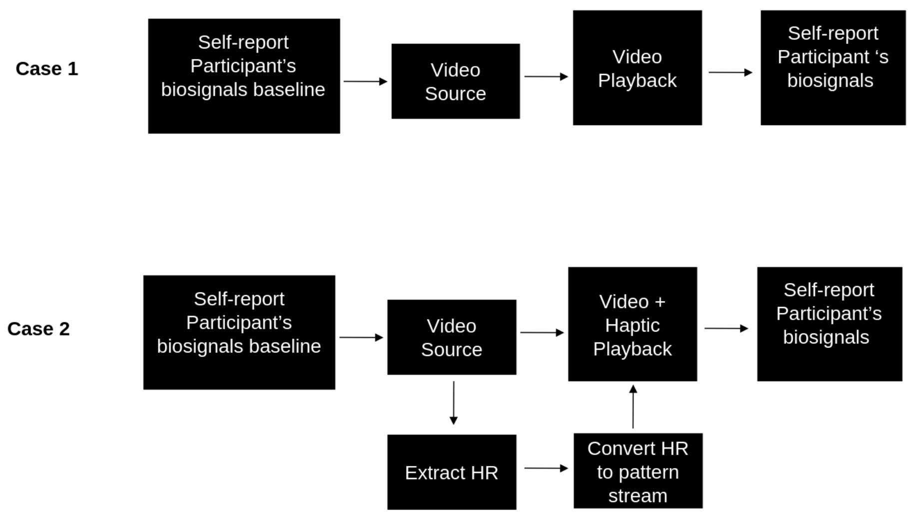

Figure 2: Two Cases applied in the experiment. In the Case 1 participants watched a video with audio-visual stimuli. In the Case 2 participants watched the video with biosignal transfer via the mid-air haptic device. The tactile pattern pulsed in accordance with the heart rate of the person in the video which was extracted in an offline phase and converted into a haptic pattern data stream.

haptically presented to the participant's palm at 120 BPM by the USX device. The quantization ranges were chosen empirically.

3.3.5 Subjective Questionnaires. Before and after the experiment, each of the participants was asked to fill out a self-report measure of affect using the PANAS questionnaire. This contained 10 items for positive feelings (e.g., excited, enthusiastic) and 10 items for negative feelings (e.g., irritable, ashamed) that can be rated on a 5-point scale. The maximum score that could be reached is 50, where the higher score represents a higher level of affect. Additionally, after the experimental condition, we interviewed the participants to investigate the emotions felt during the experiment.

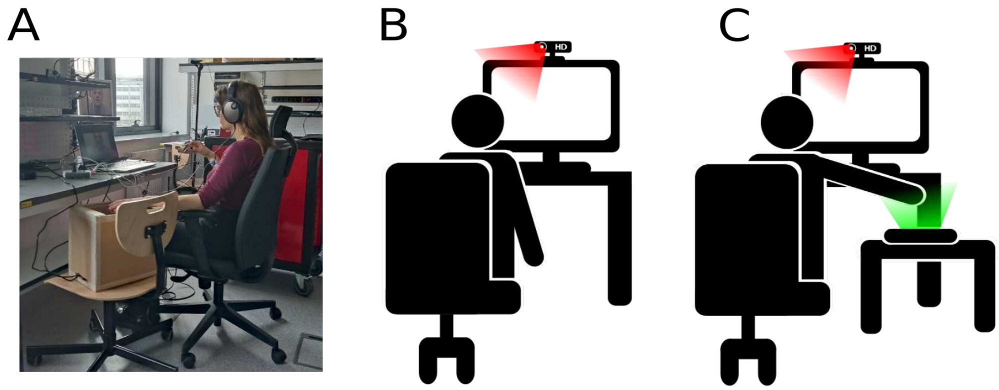

Figure 3: A) The study setup showing a participant with his left palm above the mid-air haptic device (enclosed in a box) and the right hand with the GSR sensors. B) Schematic showing Case 1, the participants only watched a video (audio-visual stimulation). C) Schematic showing Case 2, participants experienced video + mid-air tactile feedback in the form of a heart rate pattern.

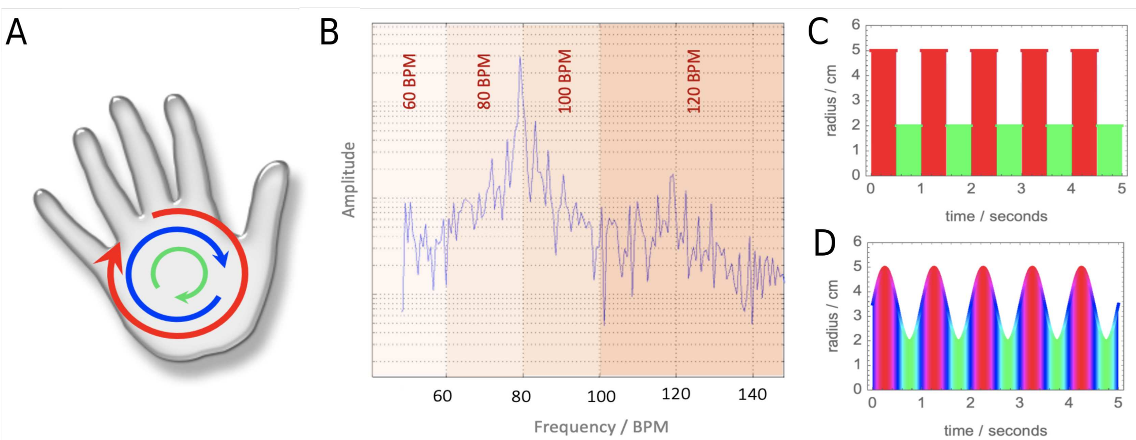

Figure 4: A - circular haptic pattern and its different sizes in reference to the heart rate frequency changes in User Study 2, B - graph representing the frequency ranges defined to generate different sizes of haptic pattern, C - the haptic pattern size change in User Study 1, D - the haptic pattern size change in User Study 2.

3.3.6 Objective Measurements. To analyse the engagement levels of participants we extracted their HR and skin-conductance. The HR was collected using the Bisosense SDK [3] which utilised a GoPro Hero 4 camera facing the participant. The skin-conductance was collected using a Grove GSR sensor with nickel electrodes attached to the right hand of each participant. The GSR signal obtained was filtered using a fourth-order Butterworth low-pass filter with a cutoff frequency of 5 Hz and normalisation before further analysis.

3.4 User Study 2

3.4.1 Participants. Thirty six new participants (mean age = 21.2 ± 5.8, 15 males, 21 females) were recruited, and the experimental procedures were approved by the local ethics committee. Participants reported that they were not under the influence of any antidepressants or other drugs affecting their mental state in the last year, and they had no impairments to their sense with touch and had no stressful or particularly significant day. All of the participants underwent the study experiment and experienced both cases and both movies.

3.4.2 Study Protocol. The protocol for user study 2 was enhanced with additional stages.

Stage 1 Welcome and Questionnaires. Similar to user study 1, but with participants also completing the STQ and SAM questionnaire.

Stage 2 Mid-air haptics familiarisation phase. Unlike user study 1, all participants were asked to experience the sensations displayed by the USX device.

Stage 3 Biosignals baseline measurements and calibration. Unlike user study 1, baseline measurements of HR, RR, and GSR were collected right before the experience for 45 seconds using additional wearable biofeedback sensors. Also, a Tobii device was situated right under the screen and calibrated to each participant in order to collect gaze and PD information.

Stage 4 Experience 1 and objective data collection. Participants experienced Movie 1 or 2 and Case 1 or Case 2, in a randomized and counterbalanced fashion. For both cases we measured a variety of participant biosignals.

Stage 5 Break and Questionnaires. Participants competed the PANAS and SAM questionnaires after which they could take a 30 minute break.

Stage 6 Experience 2 and objective data collection. Participants experienced a different Movie and Case to that of Stage 4..

Stage 7. Questionnaires and Debrief. Similar to user study 1, but with participants also completing the SAM questionnaire.

3.4.3 Study Setup. This was identical to user study 1 (see Figure 3).

3.4.4 Case 2: Haptic biosignal transfer. This was very similar to user study 1, however we updated the haptic pattern slightly. Namely, we smoothed the waveform of the beating circle pattern radius as seen in Figure 4 D, going from a square waveform to a sine. Maximum and minimum radii of the pattern as well as the quantization mapping of the different HRs were unchanged.

3.4.5 Subjective Questionnaires. In addition to the PANAS questionnaire, participants in user study 2 also completed the STQ and SAM questionnaires before and after the experiences as shown in Figure 1. The STQ contained 20 statements about different situations where touch played a major role. They consisted of positive ones (positive affect) such as petting animals, and the ones that could be described as uncomfortable (unexpected touch from others, negative affect). We evaluated them among participants in the True/False scale asking whether they agree or disagree with a given statement. The score ranged between 0 and 10 for each affect. The SAM questionnaire contained three dimensions of affective emotional responses: valence, arousal and dominance. They were measured in the 5 degree scale with the values as follows: valence (1 - happy, 5 - unhappy), arousal (1 - excited, 5 - calm) and dominance (1 - controlled, 5 - in self control).

3.4.6 Objective Measurements. Additional biosignals were measured during user study 2 to analyse the participants engagement and monitor any changes in their physiological state. Namely, we used the Neurobit Optima+ 4 BT to gather the heart's electrical activity measured with electrocardiography (ECG), electrodermal activity (EDA) and temperature changes in the exhaled air. This required electrodes to be attached to the participant's hands and additional sensors to be placed under the nose. Following data acquisition, postprocessing enabled us to extract the participants heart rate variability (HRV) and changes in skin-conductance which can be related to regulated emotional responses. To measure HRV we extracted the participant's HR, the standard deviation of RR intervals (SDNN), the root mean square of successive differences (RMSSD), the standard deviation of successive differences (SDSD), and the median absolute deviation of RR intervals (MAD). The EDA signal was decomposed into its tonic and phasic components [5]. The former refers to the slower changing elements of the signal and the latter to the faster ones. Lastly we focused on the RR and estimated it by detecting the amount of peaks in the exhaled air temperature representing the intervals where breathing occurs. Breathing changes its pattern, rate and depth in response to emotional states.

Gaze data was also captured using the Tobii Pro Fusion desktop eye tracker and Tobii Pro Lab software [48]. This set allowed us to easily collect, analyze and aggregate eye data (eyeball movement and PD) for further analysis and visualization. The device was mounted below the computer display so as not to obstruct the participant's field of view. To ensure good quality of recording it was necessary to calibrate the device before the data collection for each participant. For this purpose a pre-made calibration board with 5 markers (four in each corner and one in the center of the board) was displayed on the monitor. Participants were instructed to look at successive points on the board and for each point a calibration measurement was taken. After calibration, we proceeded to record the actual data. The Tobii Pro Lab allowed us to calculate various metrics from the recording data, namely, saccade (a rapid movement of the eye between fixation points), fixation, glance or visit metrics. We were also particularly interested in measuring changes in the PD as it has been shown to be a measure of emotional arousal because it can reflect among others a sympathetic nervous system response.

4 RESULTS

4.1 User Study 1

4.1.1 Subjective Questionnaires Results. Table 1 presents the PANAS questionnaire scores fulfilled before and after the experiment and for Case 1 and Case 2. For both conditions, there is a decrease in the positive affect and an increase in the negative affect for all participants. However, we observe more negative experiences in Case 2, than it was noted in Case 1 (displayed in bold fonts in Table 1).

4.1.2 Objective Measurements Results. Table 2 and Figure 5 show-cases the recorded HR values, the HR standard deviation and GSR tonic component values. It is important to note here that in this pilot study we used the first 45 seconds of the recorded HR and GSR data as a baseline, and the following 135 seconds as the experimental data. While not ideal, comparing the two can give some indication of any physiological changes taking place during the experience. As observed in the table, the mean HR value increased significantly in Case 1, while in Case 2 the participants HR was already high during the baseline. We attribute the high HR baseline to the mid-air haptic familiarisation phase in Stage 2 of our study protocol, which was only experienced by Case 2 participants. We also observe a rising trend when we analyze the HR standard deviation for both Case 1 and Case 2, however as we can see from Figure 5 a higher variability in HR SD is noticeable for Case 2 with haptic usage. Recall that higher HR variability is connected to higher arousal levels [6, 30, 38]. Finally, we observe a rise in the mean values and broader distributions of the GSR tonic component in Case 2, but no change in Case 1 (see Table 2, Figure 5. The increased trend of

Table 1: PANAS questionnaire mean scores for positive and negative affects.

positive affect				negative affect			
before		after		before		after	
Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
31.91	29.82	30.00	28.45	22.58	18.45	23.50	22.27

Δ +ve Affect Case 1	Δ +ve Affect Case 2	Δ -ve Affect Case 1	Δ -ve Affect Case 2
-1.91	-1.37	0.92	**3.82**

GSR tonic component is linked to stressful situations and a rise of arousal level.

4.1.3 Discussion. In User Study 1 we have performed a subjective assessment of participants affects based on PANAS questionnaires as well as several objective measurements to explore the participants engagement during the experimental setup. The questionnaires results indicate that negative emotions increased in the presence of haptic feedback. The biosignal changes showed stronger participant reaction to the presented material in Case 2, than it was registered in Case 1. Reflecting on the results of this pilot study, we decided that further measurements (objective and subjective) and more participants were needed to reach any conclusions, and also the study protocol should be adjusted to enable a within subject study comparison where all participants are exposed to the mid-air haptic familiarisation stage. These limitations and opportunities were addressed in user study 2.

4.2 User Study 2

4.2.1 Subjective Questionnaires Results. Table 3 presents the differences between PANAS questionnaire scores fulfilled before and after the experiment and for each case for positive and negative affects. For both cases we observe a decrease in positive affect and increase in negative affect in reference to the marks filled before the experiment. Scores are averaged over both movies and experiences to enable direct comparison with Table 1.

The SAM results are presented in Figure 6. From the results, it can be seen that in Case 2, participants show a greater decrease in arousal and valence than in Case 1. Before the experiment, the participants showed mostly happiness and peacefulness state (high valence) (Figure 6A). It might be caused due to familiarization phase with mid-air haptics, which happened before the experiment start. When we applied touchless haptic feedback to the experiment, participants became more sad and scared (Figure 6B), whereas without the haptics in the experiment, the dispersion in the arousal and valence of the participant was fairly similar around neutral emotion (Figure 6C).

The STQ quantifies how likely each participant would touch their co-participant for different situations. The questions concerned positive and negative affects measuring behaviors and attitudes towards social touch. The mean score for assessing positive affects was 6.81 ± 1.75 and for negative affects was 5.16 ± 2.67. A low score implies avoidance of social touch for positive affects and the opposite trend for negative affects. The STQ results showed that participants exhibited a positive attitude towards touch at the beginning of the study 2 protocol.

4.2.2 Objective Measurements Results. The participants emotional experience was assessed by the analysis of their measured biosignals (ECG, RR, gaze analysis, PD and GSR). The biosignals were applied to the preprocessing methods and parameterized to get features describing their variability. We further compared the changes in the registered signals to the baseline values separately in both cases. The results of calculated biosignals features are presented in Table 4. We compared the results in the registered signals in Case 1 and Case 2. We performed Wilcoxon rank-sum test to compare the biosignals results with and without biosignal haptic transfer. The HR mean and standard deviation values were stable in values during the experiment run as well as in comparison to the baseline measurements for Case 1 and Case 2. Note that the baselines were measured before experiment 1, not during. The mean number of breaths per minute rose during the experiment in comparison to the baseline level in both cases. Recall that emotions like fear and anxiety can cause shortness of breath, leading to an increase in the number of breaths per minute.

The mean SDSD value did not change much in Case 1, whereas in Case 2 it decreased more. The RMSSD increased in the Case 1, whereas in the Case 2 decreased. SDNN values were significantly lower in both Cases. The MAD parameter describing the variability of ECG data slightly rised in the Case 2, and decreased in Case 1. All the HRV parameters point a cardiac activity changes between both Cases. The variability of biosignals results for Case 2 point an enhanced emotional responding, what is typically linked to higher arousal levels [6, 30, 38]. For statistical analysis, Wilcoxon rank-sum test was used, cause non of the data represented normal distribution.

A statistically significant effect was found only for the GSR signal and its tonic component (p<0.02).

The biosignal results were expressed albeit at variable rates normalized to the [0-1] range to compare the location, dispersion, and shape of the data distribution of each biosignal. Looking at the box plot in Figure 7, the biosignals measured in Case 2 (with haptic) showed more outliers than in Case 1. GSR mean and RR mean results for both Cases and HR SD for Case 1 were skewed to the left (meaning that data contains larger values), whereas the rest of the measured biosignals was skewed to the right (meaning that data contain mostly low values) for both Cases. Only the MAD mean values for both Cases present symmetrical distributions.

When we compare the interquartile ranges, that is, the box lengths, the HR mean and GSR tonic mean results are more dispersed in the Case 2, meaning that the physical reaction of HR and GSR was more variate when the participant experienced the haptic feedback. Less dispersed results in the terms of Case 2 are found for

Table 2: The biosignals results from ECG: heart rate mean value (HR mean) and standard deviation (HR SD); GSR sensor: mean value of tonic component. The results are presented for baseline measurement and for further run of the experiment in Case 1 and Case 2.

	Case 1			Case 2		
	HR mean	**HR SD**	**GSR tonic mean**	**HR mean**	**HR SD**	**GSR tonic mean**
Baseline	62	2	0.46	74	3	0.51
Experiment	72	15.30	0.46	71	15.3	0.63
Difference	**10**	**13.30**	0	-3	**12.3**	0.12

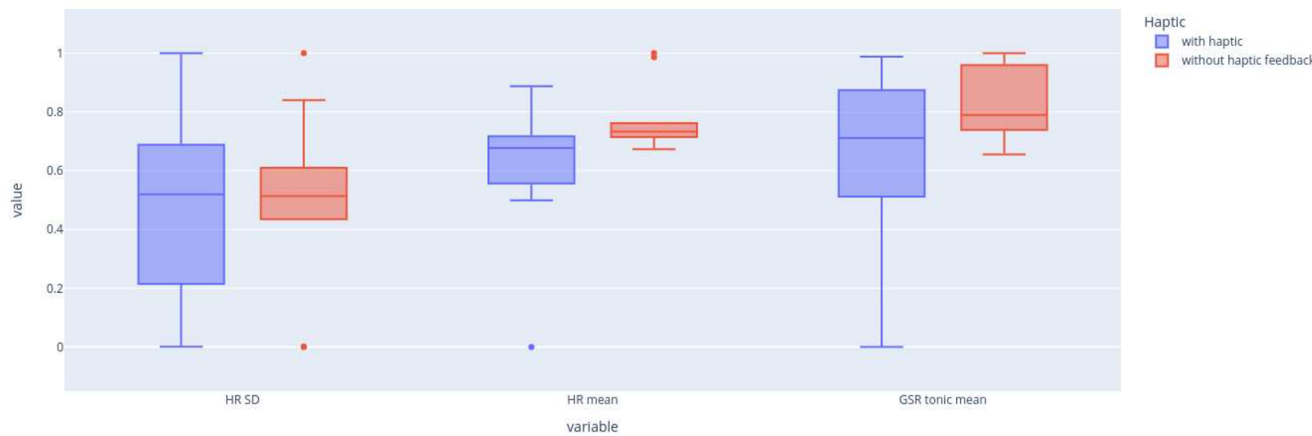

Figure 5: Distribution of biosignals measured during the experiment in User Study 1 in terms of Case 1 (red) and Case 2 (blue). * p-value < 0.05

Table 3: PANAS questionnaire scores for positive and negative affects.

positive affect				negative affect			
before		after		before		after	
Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
31.33	33.14	28.39	29.91	15.83	15.18	17.00	15.93

Δ +ve Affect Case 1	Δ +ve Affect Case 2	Δ -ve Affect Case 1	Δ -ve Affect Case 2
-2.94	**-3.23**	1.19	0.75

Table 4: The biosignals results from ECG: heart rate mean value (HR mean) and standard deviation (HR SD), mean values of SDSD, RMSSD, SDNN; GSR sensor: mean value of tonic component, respiratory rate sensor (RR mean): mean number of peaks. The results are presented for baseline measurement and during the experiment in Case 1 and Case 2.

	Case 1				Case 2			
	HR mean	HR SD	**RR mean**	**RMSD mean**	HR mean	HR SD	**RR mean**	**RMSD mean**
Baseline	82	6	20.08	54.40	83	5	24.07	64.40
Experiment	82	5	33.56	54.16	82	4	36.65	53.75
	SDSD mean	GSR tonic mean	MAD mean	**SDNN mean**	SDSD mean	GSR tonic mean	**MAD mean**	**SDNN mean**
Baseline	30.03	0.27	34.65	54.43	30.03	0.39	31.78	64.40
Experiment	28.66	0.61	29.88	54.16	25.66	0.65	32.74	53.75

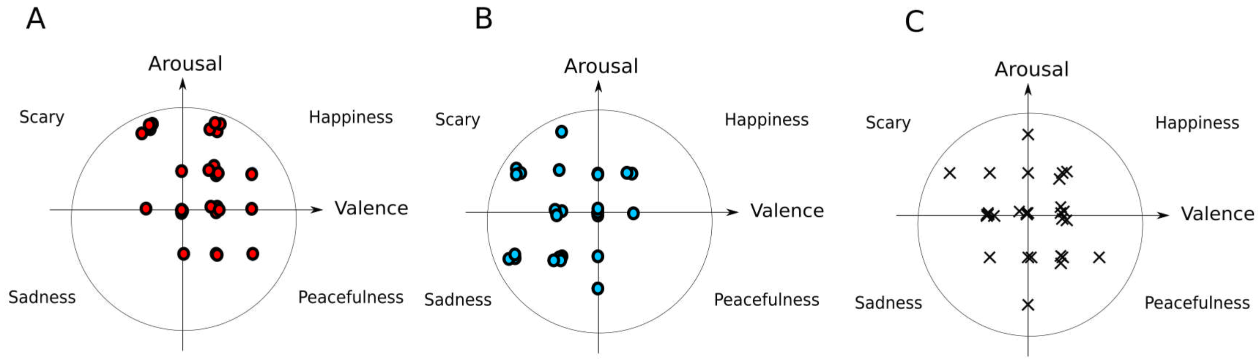

Figure 6: SAM questionnaire results for arousal and valence. A) Before the experiment. B) After audio-video stimuli with biosignal transfer using mid-air haptic (Case 2). C) After audio-video stimuli only (Case 1).

HR SD and RR mean values, in comparison to Case 1. The overall spread shown by the extreme values at the end of two whiskers is larger for all of the biosignals results when the participants experienced the sensation of haptic feedback. This indicates a wider distribution in the results, that is, more scattered data.

During the experiments, we recorded signals of gaze data. For each recording we calculated metrics such as mean number of saccades, mean and standard deviation of pupil diameter (PD), time of 1st saccades, total amplitude of saccades, time of 1st saccade, mean amplitude of saccades, mean velocity of saccades. The obtained parameter values are shown in the Table 5. Recall that a change in PD size may occur due to changes in psychological state. The mean and SD of the PD observed were similar in both conditions. Meanwhile, the mean amplitude and velocity of saccades, total amplitude of saccades, peaks velocity for 1st saccade, time for the 1st saccade, all decreased in the Case 2, in comparison to Case 1. This trend indicates that participants spatially focused their attention on the target, the person shown on the computer. Notably, the average peak velocity of saccades has also been proposed in the literature [12] as a good index of arousal. Therefore, these trends in the obtained data are a promising indication supporting our hypothesis that a multisensory biosignal transfer induces some physiological change in the participants. Finally, Figures 8 and 9 show the generated heat maps for each recording. It shows that the users gaze was mainly directed at the actor's eyes, nose and mouth, as well as the subtitles for movie 2. In both movies, the participants gaze became more focused in Case 2.

4.2.3 Discussion. In User Study 2 we have performed further subjective assessment of participants affects based on PANAS, STQ and SAM questionnaires as well as additional objective measurements to explore the participants engagement during the experimental setup which included 2 movies and 2 experiments in each run. Results and trends were in line with those observed in user study 1. Based on subjective measurements, participants in Case 2 showed a greater decrease in valence and arousal, than in Case 1. The objective measurements, like heart variability measures point cardiac activity changes between both cases. The gaze analysis showed that participants were more focused on the story shared in Case 2. Likewise in Case Study 1, the biosignals' results showed stronger participant reaction to the presented material in Case 2, in comparison to Case 1. Notably, most differences between cases were more strongly observed when comparing the distributions of the various objective measurements as shown in Figure 7.

Reflecting on the results of this study, we note that the within subject experiment faces many challenges in analysing the two cases, since each participant experiences two different movies. This makes comparing results difficult and could potentially mask further complexities and trends. These limitations and opportunities will be addressed in future work.

5 CONCLUSION AND FUTURE WORK

Based on recent literature, biosignals sharing might influence the experience of social interactions, enhancing the communication experience and interpersonal relationships. To that end, we are interested in enhancing the emotional component of our online audio-visual conversations through the haptic channel. To that end, we have developed and tested a one-way (asymmetric) multisensory (audio-visual-haptic) touchless communication system. The system comprises of a pre-recorded video of a speaker telling an emotional story. The speaker's heartrate is extracted using machine vision rPPG methods [3] and presented to the audience (study participant) using ultrasound mid-air haptic technology [8]. Thus, this multisensory experience system is completely touchless and non-invasive. To study any psychological and physiological changes two user studies engaged a total of 56 participants who completed several subjective questionnaires while a plethora of objective physiological measurements were recorded using appropriate sensors and instrumentation before and after the experiments (see Figure 1). Our results indicate that the additional biosignal transfer via the tactile communication channel enhanced the physiological responses of the participants, therefore potentially also the experience transfer or expressivity of the communication content. At the end of

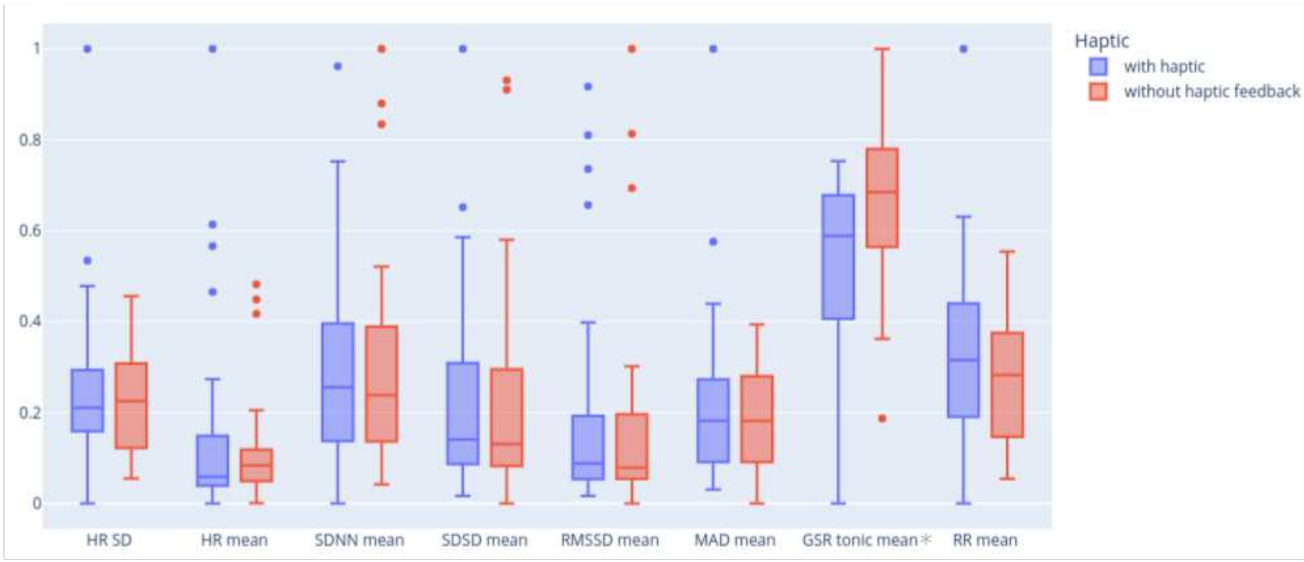

Figure 7: Distributions of biosignals measured during user study 2 experiments in terms of Case 1 (red) and Case 2 (blue). These are averaged over the two movies shown.
*** p-value < 0.05**

Table 5: Gaze data results: mean value of average pupil diameter (PD mean) and standard deviation (PD SD), number of saccades (no saccades), peaks velocity for 1st saccade (PV for 1st saccade), total amplitude (ampl.) of saccades, time of 1st saccade, mean amplitude of saccades, mean velocity (V) of saccades). The results are presented for Case 1 and Case 2.

Case 1				Case 2			
PD mean	**PD SD**	**no saccades**	**PV for 1st saccade**	**PD mean**	**PD SD**	**no saccades**	**PV for 1st saccade**
3.60	0.35	204.08	187.94	3.48	0.38	186.68	120.75
total ampl. of saccades	**time of 1st saccade**	**mean ampl. of saccades**	**mean V of saccades**	**total ampl. of saccades**	**time of 1st saccade**	**mean ampl. of saccades**	**mean V of saccades**
575.66	791.94	2.81	129.11	483.86	355.68	2.56	121.78

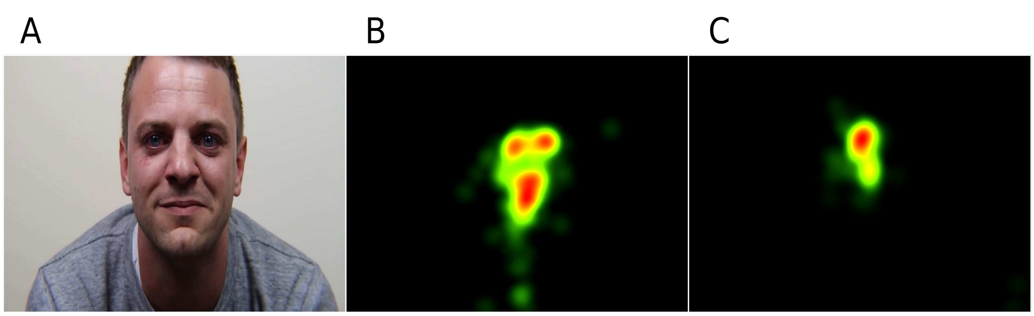

Figure 8: Gaze data heat map of Video 1, A - video screen shot, B - the gaze data heat map of Case 1, C - the gaze data heat map of Case 2.

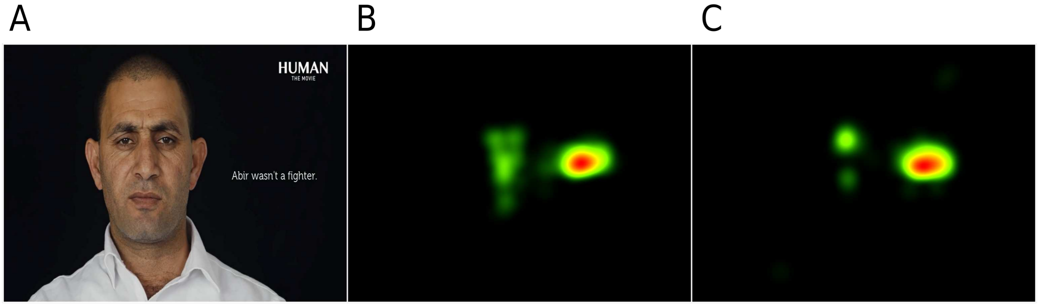

Figure 9: Gaze data heat map of Video 2, A - video screen shot, B - the gaze data heat map of Case 1, C - the gaze data heat map of Case 2.

these experiments, several participants stated that feeling the haptic biosignals indeed influenced their arousal and valence levels.

Despite our encouraging initial observations, our present investigation has raised more questions than answers, while also raising our awareness of the challenges associated with such studies. Importantly, we note the difficulty of performing controlled experiments that enable comparisons within subjects due to the novelty effects of the emotional video context and the novelty of the mid-air haptic technology. We also note that our experiments used only negative emotional scenarios. Therefore, further experiments with opposite emotions and in symmetric communication scenario are needed to strengthen and broaden our investigations, but also note that fear (negative) is for example easier to induce than happiness. Finally, while our vision for two-way communications wants to leverage a touchless multisensory system, our experimental setup required participants to rest their palm on an open box in order to experience the mid-air haptics in a consistent way. We must therefore design interaction set-ups which consider human factors and ergonomics such that users can experience the haptic biosignal communication in a more natural and comfortable manner. This could help us find applications of biosignal transfer in other areas such as digital signage, immersive exhibitions, healthcare, or voice-calls in cars.

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REFERENCES

[1] Damien Ablart, William Frier, Hannah Limerick, Orestis Georgiou, and Marianna Obrist. 2019. Using Ultrasonic Mid-air Haptic Patterns in Multi-Modal User Experiences. In *2019 IEEE International Symposium on Haptic, Audio and Visual Environments and Games (HAVE)*. IEEE, 1–6.

[2] Damien Ablart, Carlos Velasco, and Marianna Obrist. 2017. Integrating mid-air haptics into movie experiences. In *Proceedings of the 2017 ACM International Conference on Interactive Experiences for TV and Online Video*. 77–84.

[3] BioSense. 2021. *BioSense*. https://demo.softserveinc.com/biosense/

[4] Margaret M Bradley and Peter J Lang. 1994. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry* 25, 1 (1994), 49–59.

[5] Jason J Braithwaite, Derrick G Watson, Robert Jones, and Mickey Rowe. 2013. A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments. *Psychophysiology* 49, 1 (2013), 1017–1034.

[6] Anne-Marie Brouwer, Nelleke Van Wouwe, Christian Mühl, Jan BF Van Erp, and Alexander Toet. 2013. Perceiving blocks of emotional pictures and sounds: effects on physiological variables. *Frontiers in human neuroscience* 7 (2013), 295.

[7] Antonio Camurri, Gualtiero Volpe, Giovanni De Poli, and Marc Leman. 2005. Communicating expressiveness and affect in multimodal interactive systems. *Ieee Multimedia* 12, 1 (2005), 43–53.

[8] Tom Carter, Sue Ann Seah, Benjamin Long, Bruce Drinkwater, and Sriram Subramanian. 2013. UltraHaptics: multi-point mid-air haptic feedback for touch surfaces. In *Proceedings of the 26th annual ACM symposium on User interface software and technology*. 505–514.

[9] Hao Chen, Arindam Dey, Mark Billinghurst, and Robert W Lindeman. 2017. Exploring the design space for multi-sensory heart rate feedback in immersive virtual reality. In *Proceedings of the 29th Australian conference on computer-human interaction*. 108–116.

[10] Max T Curran, Jeremy Raboff Gordon, Lily Lin, Priyashri Kamlesh Sridhar, and John Chuang. 2019. Understanding digitally-mediated empathy: An exploration of visual, narrative, and biosensory informational cues. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–13.

[11] Arindam Dey, Hao Chen, Chang Zhuang, Mark Billinghurst, and Robert W Lindeman. 2018. Effects of sharing real-time multi-sensory heart rate feedback in different immersive collaborative virtual environments. In *2018 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 165–173.

[12] Leandro L. Di Stasi, Andrés Catena, José J. Cañas, Stephen L. Macknik, and Susana Martinez-Conde. 2013. Saccadic velocity as an arousal index in naturalistic tasks. *Neuroscience and Biobehavioral Reviews* 37, 5 (2013), 968–975. https://doi.org/10.1016/j.neubiorev.2013.03.011

[13] Joan Morris DiMicco, Vidya Lakshmipathy, and Andrew Tresolini Fiore. 2002. Conductive Chat: Instant messaging with a skin conductivity channel. In *Proceedings of Conference on Computer Supported Cooperative Work*. Citeseer.

[14] Andrius Dzedzickis, Artūras Kaklauskas, and Vytautas Bucinskas. 2020. Human emotion recognition: Review of sensors and methods. *Sensors* 20, 3 (2020), 592.

[15] Mohamad A Eid and Hussein Al Osman. 2015. Affective haptics: Current research and future directions. *IEEE Access* 4 (2015), 26–40.

[16] Milou A Feijt, Joyce HDM Westerink, Yvonne AW De Kort, and Wijnand A IJsselsteijn. 2021. Sharing biosignals: An analysis of the experiential and communication properties of interpersonal psychophysiology. *Human–Computer Interaction* (2021), 1–30.

[17] Cristina Fernández, Juan C Pascual, Joaquim Soler, Matilde Elices, Maria J Portella, and Enrique Fernández-Abascal. 2012. Physiological responses induced by emotion-eliciting films. *Applied psychophysiology and biofeedback* 37, 2 (2012), 73–79.

[18] Jérémy Frey. 2016. Remote heart rate sensing and projection to renew traditional board games and foster social interactions. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 1865–1871.

[19] Jérémy Frey, May Grabli, Ronit Slyper, and Jessica R Cauchard. 2018. Breeze: Sharing biofeedback through wearable technologies. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.

[20] William Frier, Abdenaceur Abdouni, Dario Pittera, Orestis Georgiou, and Rob Malkin. 2022. Simulating Airborne Ultrasound Vibrations in Human Skin for Haptic Applications. *IEEE Access* 10 (2022), 15443–15456.

[21] Oonagh M Giggins, Ulrik McCarthy Persson, and Brian Caulfield. 2013. Biofeedback in rehabilitation. *Journal of neuroengineering and rehabilitation* 10, 1 (2013), 1–11.

[22] Debbie Gijsbrechts, Stein Smeets, Jacqueline Galeazzi, Miralles Juan J, Jo Vermeulen, and Schöning Johannes. 2015. ShareABeat: Augmenting Media Shared

Through Social Platforms with Empathic Annotations. *CHI 2015 Workshop on Mobile Collocated Interactions: From Smartphones to Wearables* (2015).

[23] Hyunjae Gil, Hyungki Son, Jin Ryong Kim, and Ian Oakley. 2018. Whiskers: Exploring the use of ultrasonic haptic cues on the face. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.

[24] Shai Haiblum-Itskovitch, Johanna Czamanski-Cohen, and Giora Galili. 2018. Emotional response and changes in heart rate variability following art-making with three different art materials. *Frontiers in psychology* 9 (2018), 968.

[25] Mariam Hassib, Daniel Buschek, Paweł W Wozniak, and Florian Alt. 2017. HeartChat: Heart rate augmented mobile chat to support empathy and awareness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 2239–2251.

[26] Iris J Holzleitner, Lisa M DeBruine, Anthony J Lee, Vanessa Fasolt, Kieran J O'Shea, and Victor Kenji M Shiramizu. 2019. Social Touch Questionnaire [Reasons]. osf.io/8r9ca

[27] Gijs Huisman. 2017. Social touch technology: a survey of haptic technology for social touch. *IEEE transactions on haptics* 10, 3 (2017), 391–408.

[28] Yann Arthus-Bertrand HUMAN the movie. 2022. *HUMAN - clip 10: The struggle to belong!* https://www.youtube.com/watch?v=Nwr33vzfluQ

[29] Joris H Janssen, Jeremy N Bailenson, Wijnand A IJsselsteijn, and Joyce HDM Westerink. 2010. Intimate heartbeats: Opportunities for affective communication technology. *IEEE Transactions on Affective Computing* 1, 2 (2010), 72–80.

[30] Josiane Jauniaux, Marie-Hélène Tessier, Sophie Regueiro, Florian Chouchou, Alexis Fortin-Côté, and Philip L Jackson. 2020. Emotion regulation of others' positive and negative emotions is related to distinct patterns of heart rate variability and situational empathy. *PloS one* 15, 12 (2020), e0244427.

[31] Laura Kaltwasser, Nicolas Rost, Martina Ardizzi, Marta Calbi, Luca Settembrino, Joerg Fingerhut, Michael Pauen, and Vittorio Gallese. 2019. Sharing the filmic experience-The physiology of socio-emotional processes in the cinema. *PloS one* 14, 10 (2019), e0223259.

[32] Erin Kim and Oliver Schneider. 2020. Defining Haptic Experience: Foundations for Understanding, Communicating, and Evaluating HX. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[33] Myungho Lee, Kangsoo Kim, Hyunghwan Rho, and Si Jung Kim. 2014. Empa talk: a physiological data incorporated human-computer interactions. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*. 1897–1902.

[34] Fannie Liu, Laura Dabbish, and Geoff Kaufman. 2018. Biosignals-Driven Expressivity in Virtual Reality Avatars. In *Workshop on Novel Interaction Techniques for Collaboration in VR, CHI'18*.

[35] Fannie Liu, Mario Esparza, Maria Pavlovskaia, Geoff Kaufman, Laura Dabbish, and Andrés Monroy-Hernández. 2019. Animo: Sharing biosignals on a smartwatch for lightweight social connection. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 3, 1 (2019), 1–19.

[36] Fannie Liu, Chunjong Park, Yu Jiang Tham, Tsung-Yu Tsai, Laura Dabbish, Geoff Kaufman, and Andrés Monroy-Hernández. 2021. Significant Otter: Understanding the Role of Biosignals in Communication. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–15.

[37] Karon E MacLean, Oliver S Schneider, and Hasti Seifi. 2017. Multisensory haptic interactions: understanding the sense and designing for it. In *The Handbook of Multimodal-Multisensor Interfaces: Foundations, User Modeling, and Common Modality Combinations-Volume 1*. 97–142.

[38] Javier Marín-Morales, Juan Luis Higuera-Trujillo, Jaime Guixeres, Carmen Llinares, Mariano Alcañiz, and Gaetano Valenza. 2021. Heart rate variability analysis for the assessment of immersive emotional arousal using virtual reality: Comparing real and virtual scenarios. *PloS one* 16, 7 (2021), e0254098.

[39] Nick Merrill and Coye Cheshire. 2016. Habits of the Heart (rate) Social Interpretation of Biosignals in Two Interaction Contexts. In *Proceedings of the 19th international conference on supporting group work*. 31–38.

[40] Hyeryung Christine Min and Tek-Jin Nam. 2014. Biosignal sharing for affective connectedness. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*. 2191–2196.

[41] Jelena Mladenović, Jérémy Frey, and Jessica R. Cauchard. 2018. Dišimo. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Apr 2018). https://doi.org/10.1145/3170427.3186517

[42] Marianna Obrist, Sriram Subramanian, Elia Gatti, Benjamin Long, and Thomas Carter. 2015. Emotions mediated through mid-air haptics. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 2053–2062.

[43] Chao Ying Qin, Jun-Ho Choi, Marios Constantinides, Luca Maria Aiello, and Daniele Quercia. 2020. Having a heart time? a wearable-based biofeedback system. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*. 1–4.

[44] Ismo Rakkolainen, Euan Freeman, Antti Sand, Roope Raisamo, and Stephen Brewster. 2020. A survey of mid-air ultrasound haptics and its applications. *IEEE Transactions on Haptics* 14, 1 (2020), 2–19.

[45] Jussi Rantala, Katri Salminen, Roope Raisamo, and Veikko Surakka. 2013. Touch gestures in communicating emotional intention via vibrotactile stimulation. *International Journal of Human-Computer Studies* 71, 6 (2013), 679–690.

[46] Ted Romanus, Sam Frish, Mykola Maksymenko, William Frier, Loïc Corenthy, and Orestis Georgiou. 2019. Mid-air haptic bio-holograms in mixed reality. In *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. IEEE, 348–352.

[47] TAKE 2 THE SCREEN. 2021. *Father's final words to his dying son!* https://www.youtube.com/watch?v=C3hABRHmQoo

[48] Tobii. 2022. *Eye tracking and attention computing*. https://www.tobii.com/

[49] Chin-An Wang, Talia Baird, Jeff Huang, Jonathan D Coutinho, Donald C Brien, and Douglas P Munoz. 2018. Arousal effects on pupil size, heart rate, and skin conductance in an emotional face task. *Frontiers in neurology* (2018), 1029.

[50] David Watson, Lee Anna Clark, and Auke Tellegen. 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology* 54, 6 (1988), 1063.

[51] Christian JAM Willemse, Dirk KJ Heylen, and Jan BF van Erp. 2018. Communication via warm haptic interfaces does not increase social warmth. *Journal on multimodal user interfaces* 12, 4 (2018), 329–344.

[52] R Michael Winters, Bruce N Walker, and Grace Leslie. 2021. Can You Hear My Heartbeat?: Hearing an Expressive Biosignal Elicits Empathy. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–11.