Having a heart-to-heart

Exploring the capacity of heartbeat-feedback to mediate affective information in interpersonal communication

Bernd Dudzik
Graduation Thesis, August 2015
Media Technology MSc program, Leiden University
bernd_dudzik@hotmail.com

Supervised by: Dr. Peter van der Putten, Leiden University
Dr. Joost Broekens, TU Delft

***Abstract*— In this study we explore whether having access to other person's heartbeat-signals has the capacity to act as a nonverbal channel for the exchange of affective information. Within an experimental setting (N=33) we exposed sender-subjects with emotional stimuli that varied in the level of emotional intensity that they induced. Simultaneously, non-collocated receiver-subjects were provided with vibrotactile representations of senders' heartbeat-signals, and tasked to judge whether the signal had been caused by exposure to either a stimulus of low or high emotional intensity. Cases of successful mediation of affective information were defined as the agreement between receivers' choices with senders' self-reported affect. Results demonstrated that the average rate of successful mediation of affective information for sender-receiver couplings was significantly larger than what might have been expected by random chance. This finding highlights the potential of heartbeat-signals as a nonverbal channel for the communication of affective information. Implications for applications and future areas of investigation are discussed.**

***Index Terms*— affective computing, affect mediation, computer-mediated communication, affect-aware assistive technology, affective communication technology, physiological signals**

I. Introduction

Apart from verbal communication, our understanding of others' emotions is primarily the result of empathic processes that involve the interpretation of a variety of nonverbal cues [1]. During personal interaction, changes in features and constellations of facial expressions [2], the tone of their voice [3], or body postures [4], [5] provide constant hints about others' thoughts and feelings.

However, while changes in these characteristics of their physiology are accessible for our interpretation of others feelings, others are not: psychophysiological investigations have uncovered that numerous components related to the *autonomic nervous system (ANS)* – the branch of the peripheral nervous system responsible for regulating the functioning of the internal organs and managing the body's energy expenditure [6] – are impacted by emotional functioning as well [7].

The origin of this connection is assumed to be found in our early evolutionary heritage, where emotions evolved as distinct categories of adaptive response mechanisms to situations that demanded rapid and coordinated actions across different systems to ensure the survival of the organism [8], [9]. Autonomic activity is considered to be an important part of these responses, having the purpose of preparing the body for drastic actions, e.g. fleeing from a suddenly emerging predator, or getting ready to fight it off [10]. Several prominent theories of emotion are based on the notion that feeling these physiological reactions unfolding in our own bodies plays a crucial role in defining the experiences that we call emotional [11]–[13].

The field of affective computing is actively searching for means of exploiting this relationship to empower computers and robots with emotional understanding: sensors quantify physiological activity into numerical data, that is then used in attempts to predict users' affective states allowing computer systems to adapt their functioning in response to this information [14]. While the primary driving force behind this research is the improvement of human-computer interaction, a strain of research also investigates the potential of technology to enhance human beings' emotional understanding of each other [15], [16].

One approach to make the psychophysiological meaning of biosignals accessible within interpersonal interaction might be to render these normally invisible components perceivable through technology [17]. Various projects have explored feedback based on biosignals to augment face-to-face interactions [18], or mediated communication systems [19], [20] by acting as additional sources of affective information.

An example for such a system can be seen in a wearable device developed by Picard and Scheirer [18] dubbed the *Galvactivator*, which measures the electrodermal activity of its wearer – a well-known indicator of emotional arousal [21] – and makes it accessible for others by displaying it as the brightness of an integrated LED.

A promising candidate to be used within this approach may be feedback representing the beating of the human heart. It is one of the most widely measured responses connected to autonomic activity during emotional functioning and was found to be impacted across a broad range of different emotional categories [22]. Moreover, in contrast to many other physiological reactions occurring during emotional episodes, people have interoceptive access to their own cardiac activity in the form of a pulsed signal that they can keep track of, and the degree of this awareness was found to impact both the quality [23] and intensity [24], [25] of their emotional experiences.

Furthermore, empirical results demonstrate that heartbeat-signals are capable of conveying some of the meaning that psychophysiological investigations have associated with them also to human beings that interpret them. In a laboratory study Janssen et al. [26] manipulated heart rate and heart rate variability of artificially constructed heartbeat-signals in order to study the impact of these changes on participants attributions of emotional intensity. Their findings revealed a positive correlation between the tempo of the heartbeat-signal and the amount of emotional intensity that participants assigned to it. Moreover, in the same study they showed that participants interpreted the emotional intensity of fast and slow heartbeat-signals similarly to that of emotional and neutral facial expressions. This connection is largely congruent with actual changes in cardiac activity during a broad range of emotional experiences, many of which entail an increased heart rate [22].

Similar results have emerged in earlier studies on the effects of false autonomic feedback [27]. Valins provided [28] participants with bogus representations of their own heartbeats alongside a series of emotional stimuli. Manipulations of tempo and direction of the feedback led them to judge a stimulus as having an increased emotional impact on them.

Because emotional experiences have been associated with the change of patterns in cardiac activity, and because individuals associate changes in heartbeat-signals as an indication of varying levels of emotional intensity, we expect that having access to another person's heartbeat can mediate information about the intensity of their affective state.

Previous research projects have incorporated the transmission of heartbeat-signals in technological prototypes for interpersonal communication, but their focus has rested either on questions of design and technological conception [29]–[31], or on the exploration of effects in the context of social connectedness and intimacy [17], [32] . However, no attempt has been undertaken to empirically explore the potential of such a system for affective communication. Therefor, in this study we explore the capacity of heartbeat-signals to act as a medium for the transmission of information about their owners affective state.

To conduct this investigation, we constructed a wearable device that allows measurements of one person's heartbeat to be transmitted to a second person, where they are recreated in the form of a beat-by-beat vibrotactile representation. Using this device to connect two participants in a sender-receiver setting, we evaluated the ability of receivers to successfully relate to the intensity of affect experienced by senders while they were being exposed to a series of emotional stimuli.

The remainder of the paper is structured as follows: In *section II* we aim to contextualize this research by describing the motivation behind the development of technology dealing with the communication of affect. In *section III* we give a detailed description of the experimental setting that we conducted to investigate our research question, the results of which we describe in *section IV*. Finally, in *section V* we discuss our findings and describe their potential implications for the development of affect mediation technology drawing on heartbeat-feedback. In addition, we outline a general research agenda for potential targets of future investigations of heartbeat-feedback in specific, and the usage of physiological feedback as nonverbal channels for affect mediation in general.

II. Background and Motivation

Emotional expressions and behavior function as powerful source of information in social interactions; they provide insights about others' appraisals of an object or a situation, as well as their potential behavior and intentions [2]. The resulting empathic processes can have a profound influence on observers' own affective states as well: they do not only *understand* how the other is feeling, but they *share* this feeling to a certain degree [33], [34]. For instance, the empathic attuning to the distress of others is a crucial motivation for pro-social behavior and sympathy between human beings [35].

Likewise the expression of emotions plays a decisive role in the emergence of social structures by fostering cohesion or exclusion between groups and individuals [36]. Empirical findings indicate that individuals are more likely to share emotions when interacting with someone close to them [37] and do so more intensely [38]. This sharing of emotions is part of the formation of intimate bonds between human beings, but also a mechanism for strengthening and maintaining them [39], [40].

Unfortunately, there are conditions where the body's natural capabilities are unable to fulfill their usual role at supporting emotional expression and awareness, be it because their correct functioning is impaired due to physical damage – for example as the result of severe injuries of the sensory or motor system [15] –, or due to a complex affliction like autistic spectrum disorder [41]. Typically communication technologies exercise a limiting effect on the fidelity of socio-emotional interaction as well. For example, certain forms of *Computer-mediated communication (CMC)* facilitate the explicit expression of emotions, but do not convey the same sense of implicit awareness of other individuals' affective state that is offered by nonverbal cues in face-to-face interaction [42].

Because of the important role of emotions within human social interactions, ongoing research in the fields of *Human-Computer Interaction* and *Affective Computing* is investigating technological solutions to improve their expression under these conditions. One example for this undertaking can be seen in the development of a*ffect-aware assistive technologies* that aim to counteract the limiting impact of physical impairments on the expression of emotions [15] , while *affective communication technologies [16]* and systems providing implicit emotional awareness [20] aim to improve existing ways of socio-emotional interaction through technology.

III. Experimental Setup

To evaluate the capacity of mediated heartbeat-signals to facilitate the exchange of information about the intensity of others' affective state, we adapted a sender-receiver setting similar to the one deployed by Buck et al. [43], [44]. They describe a setup in which a *sender* is presented with different categories of pleasant and unpleasant slides, while being watched by a non-collocated *receiver* through a CCTV-system. Receivers are tasked with associating a category from a list of options that they deemed to best fit the stimulus that caused senders' responses. Through comparing the categories of receivers' judgments with the category of stimuli that senders are exposed to, this procedure results in a basic behavioral measure of spontaneous facial expressions to facilitate the exchange of information about the affective states in question. The physical separation of participants in this setting excludes the influence of other communication channels.

To accommodate this setting for the present study, we substituted the exposure of receivers to spontaneous facial expressions with the exposition to beat-accurate representations of senders' heartbeat-signals. We manipulated the level of intensity of senders affective states between low- and high-levels and asked receivers to choose the type of stimulus that they thought might be a plausible cause for the resulting heartbeat-response. Their choices consisted of one high intensity and one low intensity option.

With respect to this experimental setup, our general hypothesis that heartbeat-feedback is capable of mediating information about the intensity of senders' affective state can then be operationalized in the following way:

> **H1:** Receivers will associate high intensity stimuli with heartbeat-signals from situations in which senders reported to be in a high intensive affective state, and associate low intensity stimuli with heartbeats from situations in which senders reported to be in a low intensity affective state to a degree that is significantly above random chance.

TABLE I. Distribution of participants according to age, gender and occupation

Gender		
Male	***Female***	
21	12	
Age		
18-27	***28-43***	***44-60***
22	9	2
Occupation		
Professional	***Student***	
14	19	

A. Participants

A total of 34 subjects were recruited for the study, of which *33 (m=21, f=12)* successfully completed it. The data of one participant was damaged due to a technical defect. See *Table I* below for an overview over demographics of the sample.

B. Material

The experiment was conducted at the *New Delft Experience Lab* at the Delft University of Technology. Two identical tablet-computers were used to run custom software that provided instructions to the participants, controlled the exposure to stimuli, and collected rating-data.

To facilitate the transmission of heartbeat-feedback a system of wearable devices has been developed specifically for this experiment, which allows receivers to access a beat-by-beat representation of senders' heartbeats in the form of vibrotactile pulses on their wrists. Senders' equipment consisted of a Polar H7 heart rate-monitoring chest belt to measure participants' cardiac activity in the form of *inter-beat intervals (IBI).* This measurement represents the duration between two consecutive beats, and as a result contains information about both the general speed at which the other's heart is beating (i.e. heart rate) as well as slight variations in the timing between individual heartbeats (i.e. heart rate variability). Previous research found both of these features to be of relevance for participants interpretations of a heartbeat-signals emotionality [26].

In line with the usage of auditory representations of heartbeat-signals in earlier studies [17], [26] the duration of each pulse defaulted to 500ms. However, to keep consecutive beats distinguishable from one-another at individual IBIs below 500ms (corresponding to a heart rate of above 120 bpm), the pulse duration was adjusted for these cases in the following fashion:

$$PulseDuration_{ms} = 0.9 * IBI_{ms}$$

Sensor displacement and movements can lead to erroneous readings, which manifests itself exceptionally large or small IBIs. Since these might influence the way that receivers interpret the heartbeat-signal, we applied filtering based on the situation of the experiment to compensate for artifacts: IBIs below 333ms (equal to a heart rate of ~180 beats per minute) were not transmitted, while individual IBIs above 1700ms (equal to a heart rate of ~35 beats per minute) were split up and interpolated using a running average.

C. Methods of Assessment

As a basis for identifying emotional impact of a stimulus on senders we collected their self-reports of experienced affect in terms of *pleasure-, arousal-, and dominance (PAD)*-dimensions using the *AffectButton*-instrument described in [45]. It presents users with an iconic facial expression that dynamically changes with mouse or touch interaction, and allows them to report their affective state in a manner that is both *nonverbal* and *implicit*. The following instructions were used in combination with the rating task: *"How did watching the movie make you feel? Move your finger over the surface of the face depicted above until its expression matches your experience as closely as possible. You can change your rating as often as you like before continuing."*

Because instruments for quantifying emotional experiences include implicit theoretical assumptions about the structure of affect, we need to briefly introduce the PAD-model to motivate its usage in context of this study. The PAD-model is a widely used method to describe affective phenomena in terms of a set of underlying dimensions or factors. Instead of classifying emotions as members of discrete categories – e.g. anger, sadness, or neutral – factor-based theories provide a description of an experience's underlying *affective core* within a continuous space [46]. Consequently, to describe an emotion within the PAD-framework means to assign it a specific position within each of the three orthogonal dimensions of *pleasure* (how positive or negative is the experience?), *arousal* (how much bodily activation or alertness are involved in the experience?), and *dominance* (how much control do I feel over my environment during the experience?) [45].

The individual dimensions in PAD-space stretch out into two directions from a central point of origin, which designates neutrality, into positive and negative extremes. So might *sadness* be placed in a region with negative pleasure (-P), negative arousal (-A) and negative dominance (-D), while *elation* might be described as having positive pleasure (+P), positive arousal (+A), and positive dominance (+D).

Within such a dimensional representation of core affect, the *quality* of an affective experience is represented by the proportion of the different coordinates in relation to each other, while its *intensity* can be seen as encoded in terms of their deviation from a neutral affective state, i.e. the absolute values [47]. Consequently, each dimension contributes equally to shaping the experienced intensity: a feeling with a neutral arousal-component can still be considered intense, provided it scores high on the other dimensions. In mathematical terms this conception of PAD-intensity can be expressed as the magnitude of a vector from the coordinate origin of PAD-space.

In the context of the AffectButton each dimension is quantified in a normalized range between *-1* and *1*. However, because of the specific way that it internally maps the three-dimensional PAD-coordinates to the two-dimensional representations of facial expressions it shows to users, values along the arousal-dimension have to be interpreted differently than those for the other dimensions: instead of *0* representing the lowest possible intensity as is the case for pleasure and dominance, this state is here represented by the value of *-1*.

The following formula reflects this state of affairs, and has been used within this study to derive an integrated measure of senders' *intensity of experienced affect (IA)* from the collected PAD-values:

$$IA_{pad}=\sqrt{p^2+(a+1)^2+d^2}$$

To assess receivers' ability to relate to senders' affective state we used *a dichotomous selection task* in which they were asked to select the stimulus that they thought to be the potential cause behind the heartbeat-signal that they had received from senders. They were always offered with two potential choices – one associated with low and one with high intensity affect. Instructions provided with the differentiation task were: "*Which of these two film clips do you think the sender has been watching?"*

D. Stimuli

Film-clips for the usage in the experiment were extracted from sets that had been suggested by previous studies [48]–[51], or from stock footage possessing comparable qualities.

A stimulus was considered to be of low intensity when it was associated with a neutral emotional category, or had been associated with neutral valence and low arousal-levels. These clips were expected to induce and be associated with *low intensity affective experiences.* Membership in the *high intensity* category was based on a stimulus' association with a discrete emotional category that has been found to reliably impact measurements of cardiac activity (amusement, anger, disgust [22]), and/or high ratings of positive or negative valence, as well as arousal. These stimuli were expected to cause and be associated with *affective experiences of a high intensity*.

In an informal pilot-experiment, low intensity stimuli with a duration longer than 3 minutes seemed to cause participants in both sender and receiver roles to lose patience and show signs of annoyance. Therefor, stimuli above 3 minutes were filtered out, or trimmed in length where this seemed possible without destroying their capability to convey their target emotions.

E. Procedure

Both participants were greeted together and briefed in detail about the structure of the experiment. This especially included a detailed warning that some of the stimuli used within the experiment to induce emotions were selected to spark intense negative experiences. Once they had confirmed that they had understood their task, and the potential risks involved, their informed consent was obtained in writing. They were then assigned to their initial roles as either a sender or a receiver, before being relocated to separate rooms.

At each location the experimenter provided instructions on how to handle the equipment needed for their task. Part of this introduction included the information that their counterpart was situated in identical conditions to themselves, i.e. seated on a chair, using the same kind of equipment.

Initially, both participants were tasked to simultaneously watch a set of six film clips – consisting of three low and three high intensity options. They were then informed that three random clips from this set would be presented to their counterpart during the experiment. Participants were then asked to view all the clips until they themselves were of the opinion that they had sufficiently understood the emotional meaning of each, before proceeding with the experiment. From here on the experiment progressed in different ways for either subject, depending on their respective role.

The overall procedure per experiment consisted of a block of three trials per participant, which were in turn structured as a linear progression through three distinct phases.

Upon completion of one block, participants' roles were switched and the equipment between them was exchanged. Hence, every participant did undergo the experiment in both roles.

Each trial started with a *baseline-phase* in which neither senders nor receivers were exposed to a stimulus for a period of 30 seconds. Receivers were provided with heartbeat-feedback of senders during this phase, in order to offer them a reference point known to contain no manipulation of senders' affective state.

In the following *exposure-phase*, a single stimulus was presented to senders, which was randomly selected from within the set that receivers had explored before. While senders were viewing the clip, receivers were provided with their heartbeat-signals as feedback.

A trial was concluded by an *evaluation-phase* where ratings from both participants were obtained. Senders were asked to describe their emotional experience in response to the stimulus that they had been presented with as accurately as possible. Receivers were tasked to select the one of the two potential options that they deemed most likely to be the movie clip that had caused the heartbeat-signal that they received during the exposure phase from the sender. These options were presented in the form of still images representing specific movies belonging to the set that receivers had explored at the beginning of the experiment. Each pair consisted of one high intensity choice and one neutral choice. After a selection had been made, both choices were removed from the pool of potential options for the remaining trials of the block.

IV. Results

In this section we give an overview over the results obtained from the experiment described above, over the procedure that was used to classify cases of successful mediation of affective intensity, and the evaluation of our hypothesis.

A. Classification of self-reported affect

The intensity of the affective state that has been induced in senders by a stimulus was derived from subjects' self-reported values of their *intensity of* self-reported *affect (IA).* We first conducted a median split *(Mdn = 1.466)* to segment the collected *IA-values (n = 99, M = 1.263, SD = .998)* into two distinct proportions. Observations above (and including) the median *(n = 50, M = 2.173, SD = .29)* were classified as situations that caused in senders a *high intensity affective state (high-IA),* while data-points belonging to the proportion below the median *(n = 49, M =.336 , SD = .41)* were considered to represent situations in which a stimulus resulted in senders being in a *low intensity affective state (low-IA)*.

B. Classification of successful mediation of affect

Based on the classification of the emotional impact in observations, *successful mediation of affective information* between senders and receivers was defined as those cases were receivers chose a low intensity stimulus and a sender reported a low-IA, or where receivers had selected high intensity stimulus and senders' reported high-IA. See *Table II* below for an overview of the classification scheme for successful exchanges.

C. Manipulation checks

Congruent with the intended induction-pattern of two distinct levels of intensity in senders' affective states. a Welch two sample t-test showed a significant difference between high-AI and low-AI groups in terms of their self-reported affect *($t = 25.7$, $df = 86$, $p<0.01$).*

There might have been an inherent bias in the stimuli that were presented to receivers in the dichotomous selection task which might have lead to them to be selected or avoided independently of the heartbeat-signals that accompany them, e.g. due to aesthetic preferences. To account for this possibility, we compared the proportion of selections at which each stimulus was chosen in total over all the occasions during which it had been presented to receivers, against what would have been expected in case of a random selection (.5). Results showed no significant deviation for all stimuli *(one binomial-*

TABLE II. Scheme used for the classification of successful affective exchanges

Sender	Receiver's	
	High Intensity	***Low Intensity***
High Intensity	Successful	Unsuccessful
Low Intensity	Unsuccessful	Successful

test per stimulus, two-sided). This indicates that without accounting for its role in the experiment, there is no systematic pattern to whether receivers selected a specific stimulus or not.

D. Hypothesis testing

According to the outlined classification scheme, successful exchanges of affective information from senders to receivers occurred in 60.6% of all trials within the experiment. A detailed view of the pattern of successful mediations by level of affective intensity can be found in *Table III* below.

To evaluate the overall capacity of heartbeat-feedback to enable the successful exchange of affective information from senders to receivers, we performed an analysis of individual sender-receiver proportion of successful affective exchanges over their block of trials *(n=33, M=.606, SD=.306).* Results of a one-sample t-test against the rate that would be expected by random chance *(M=.5)* indicated a significant positive difference (*p= .027, df=32, t=1.993, one-tailed).*

This finding lends support to our hypothesis that having access to other persons' heartbeat-signals can mediate affective information about their emotional experiences.

To control for potential effects of the order in which participants were assigned their roles within the experiment, we additionally compared the rates of successful exchanges between those participants that first assumed the role of senders, and those that first assumed the role of receivers. A Welch Two Sample t-test showed no significant divergence between the two results *(df=28, t=1.172, p=.251)*, indicating no effect of role on the success-rate of affective exchanges.

A more detailed comparison of the proportions of cases of successful mediation by their level of affective intensity revealed that high intensity affect was mediated more successfully than random chance would predict *(p=.016, binomial test, one-tailed),* while this was not the case for low intensity affect *(p=.196, binomial test, one-tailed).*

To investigate whether the presence of high intensity affect had a systematic influence on the success between sender-receiver couples within the experiment, we computed a Pearson product-moment correlation coefficient between the amount of their successful trials and the amount of cases of reported high-intensity affect in their respective blocks. Results indicated no significant correlation between the two variables *(r =.003, n=33, p=.986).*

TABLE III. CONFUSION MATRIX FOR CASES OF SUCCESSFUL MEDIATION OF AFFECTIVE INFORMATION.

Sender	**Receiver**	
	High Intensity	***Low Intensity***
High Intensity	**32 (64%)**	18 (36%)
Low Intensity	21 (42.8%)	**28 (57.2%)**

V. DISCUSSION

In this study we explored the potential of a beat-by-beat representation of one person's heartbeat-signal to enable the mediation of information about the intensity of the emotional impact that a stimulus had on them to another person. We successfully induced high- and low intensity affective states within senders,and recorded the category of stimuli that receivers judged to be the cause for the resulting heartbeat-signal.

We hypothesized that if mediated heartbeat-signals contain meaningful information about senders' experiences of emotional intensity, receivers' judgments and senders' self-reports would agree a significant amount of times in the level of affective intensity that they signify. Our findings indicate that the average rate of successful exchanges across sender-receiver dyads was significantly higher than what might be expected by random chance alone. This result points to the potential of heartbeat-signals to form a nonverbal channel that possesses the capacity of exchanging information related to the intensity affective states between two individuals.

The ability demonstrated by receivers in our study to relate to senders more often than not without having any prior training or practice supports the suggestion made by Janssen et al [26] that the mechanism behind the interpretations of others' heartbeats is the intuitive familiarity of interpreters with their own heartbeat-signals during emotional functioning.

However, despite the overall capacity of heartbeat-signals to allow receivers to relate to senders' affective states, not all sender-receiver couplings were equally successful: for some of them all trials ended with a successful mediation, while for others heartbeat-feedback did allow any form of affective exchange at all.

Our findings indicated a potential influence of the level of intensity of the affect that is exchanged on the successful outcome of the mediation process. Trials involving high intensity affect were generally more successful than trials involving low intensity affect. However, the presence of high intensity affect in senders was not able to account for the increased success of certain sender-receiver couplings.

In this sense it may be beneficial to conceive of empathic processes based on heartbeat-feedback as possessing a similar structure to those based on natural nonverbal channels: their capacity to facilitate successful understanding within interpersonal interaction is not an inherent quality of the channel over which it takes place, but instead emerges as the result of an interpersonal process between the individuals participating in it. As such, it is dependent on dispositions of both the person making the inferences and the person that they concern [52].

As such, variations in the success of different sender-receiver pairings may result from numerous influences on both the connection between emotional experiences and the heartbeat-signals accompanying them on the side of senders (the “encoding” of the affective information), or on the inability of receivers to interpret these signals accurately (the "decoding" of the affective information).

Indeed, it maybe that the heartbeat-signals of certain senders generally vary in how easy they are to read for others. An anecdotal example for this is provided by the observed performance of one sender-receiver couple in this study. Being a trained athlete the tempo in the heartbeat-signal of the sender-subject was very low, and seemed to be changing only mildly, independently of the emotional impact that he reported stimuli to have on him. The receiver-subject in this couple did not manage to draw on his heartbeat-signals to relate to his affective state within a single of the trials in this constellation.

In a similar fashion, given that familiarity with ones own cardiac activity is likely involved in the mechanism that steers individuals ability to interpret heartbeats-signals [26], it may well be that the level of cardiac awareness that a specific receiver possesses also provides advantages at accurately interpreting the emotional meaning of others' heartbeats.

Hence, a possible reason for the increased rate of success of heartbeat-feedback when it comes to the mediation of high intensity affect might be a general difference in the salience of the affective information in the accompanying heartbeat-signals, that cannot be registered by all receivers.

A. Limitations

There are several limitations to the degree that the results obtained from this study can be generalized beyond the scope of this experimental setting.

For once, having access to someone else's heartbeat is not a natural phenomena, but is facilitated through a technological device that presents participants with a representation of measurements of the cardiac activity of another person. As such, there are idiosyncratic characteristics in the form in which the heartbeat-signal was translated and presented to receivers that resulted from the design decisions that we made in its construction. Some of them, might have had an influence on the results, such as the duration of the pulses for individual heartbeats, the position of the actuator on the skin, or the way that the device recognized and interpolated faulty heartbeat-measurements. We tried to account for these facts by making all relevant design decisions explicit in the materials section, so that they are reproducible and their potential impact can be assessed.

Furthermore, there are aspects of the evaluation procedure that may have had an influence on the results that we have obtained. One such constraint is that we implicitly rely on the agreement between the a priori classification of film clips as either associated with low or high affective experiences and the meaning that receivers themselves associated with them. Explicit self-reports of the affective qualities that they assigned to the stimulus might therefor be a useful improvement to bolster the validity of the data generated by the selection task in future investigations.

Moreover, it is possible that the forced-choice dichotomous selection task which has been used to assess receivers ability to relate to the heartbeat-signals resulted in measurement artifacts that influenced the size of the effect. While the experimental procedure used in this study does not shed light on the confidence with which they made their choices, many participants reported after the experiment that they judged the task as being difficult and that they were unsure about the correctness of their judgments. This could indicate that individuals' interpretations of others' heartbeat-signals are likely captured better in the form of varying degrees of certainty or intensity, than along a sharp categorical boundary.

While senders' self-reports indicate that the induction of different levels of emotional intensity was successful, it is possible that this did not entail a physiological response in all cases. Prototypical emotional responses that involve a coherent response of experiential, behavioral and physiological components are notoriously difficult to elicit with ethically acceptable laboratory procedures, and the presentation of film clips is no exception in this respect [48]. Under which conditions such coherence in emotional responding exists is generally debated among the scholars of emotion, and despite indications that the intensity of the accompanying experiences exercise an influence on its manifestation, findings indicate that even then components might not react uniformly across different emotions [53], [54]. Since we presented sender-receiver pairs with stimuli that were selected to be clearly different in the level of emotional intensity that has been associated with them, but independently of their membership to a specific emotion category, their impact on receivers cardiac responses might have been different. We tried to minimize this influence by selecting only stimuli from emotional categories that had been suggested by previous research as being generally able to elicit cardiac reactions.

Additionally, there is evidence that age plays a role for the intensity of emotional reactions that films are able to elicit in participants [51]. Since the majority of the subjects within the study were male university students between 18-27 years, this might have had an influence on the objective level of intensity that we could elicit, and as a consequence on the results of the experiment.

B. Applications

The results of this study indicate that having access to a person's heartbeat-signal allows a recipient to relate to the affective state of its owner. This opens up potential applications in a broad variety of domains.

So could heartbeat-feedback be implemented to augment existing forms of text-based computer-mediated communication with an additional nonverbal channel that offers their users awareness of each others' emotional reactions to their messages.

In a similar way heartbeat-signals that are coupled to text messages might act as an additional signal for the intensity of the explicit aspect of the message. Other forms of mediated communication that reduce the range of nonverbal cues for empathic understanding between their users, e.g. voice-only communication, might be augmented similarly.

Especially interesting for applications is the emergence of wearable technology that has the capacity to incorporate sensors for physiological signals and actuators to provide feedback in various modalities in an unobtrusive way. These systems could allow heartbeat-feedback to be constantly accessible to the immediate surroundings of their users, and as a result form a permanent additional source of meaningful affective information about their wearers.

Providing feedback of a person's heartbeat to others does not depend on that person having to have a functioning motor system. As a consequence, heartbeat-feedback might be of use in assistive technologies that aim to enhance the affective expressions of individuals whose natural capacities are hampered by an affliction, such as patients that suffer from Parkinson's disease [55].

Similarly, because heartbeat-signals can be rendered tangible using different modalities, they might be able to form a channel for the exchange of affective information that is also accessible to individuals with sensory impairments, such as the blind or the deaf. However, due to the fact that heartbeat-signals need to be *made accessible* by their owners, and cannot be accessed unilaterally by recipients, it is likely only viable option for this purpose within constrained contexts, and not as a general means to enhance emotion recognition.

C. Future Research

While the results of this study offer preliminary insights into the capacity of heartbeat-signals to act as a channel through which affective information can pass, they point to a broad range of targets for further investigations.

In our understanding, the findings of this work could be expanded on three meaningful ways: (1) through a continued focus on the effect of heartbeat-signals in isolation that has been indicated by the findings of this study, (2) an exploration of the potential of other physiological signals as nonverbal channels for affective exchange to produce similar effects, or (3) an investigation of the interaction of heartbeat-signals with other communication channels. In the following we will briefly outline some of the issues that research could address for each of these areas.

1) Effects in isolation

Questions that might be addressed in further in-depth investigations of the capacity of heartbeat-signals within affect mediation systems might focus on their capacity to allow the exchange of more specific information, the impact of the form in which the heartbeat-signals are represented on their interpretation by receivers, as well as an investigation of contextual factors on the emergence of successful affective exchanges.

While cardiac activity on its own does not contain information that allows a unique identification of specific categories of emotion, certain emotions have been reported to differ reliably from one another in various metrics of cardiac activity during their response [22]. It could be insightful to examine the potential of heartbeat-signals to allow receivers the differentiation between these specific types of emotional experiences of another person.

An important aspect that has been largely overlooked in research on the provision of artificial heartbeat-feedback is the relationship between the *form* of their representation and their *meaning*. Different modalities have been used to render heartbeat-signals tangible in psychological studies and communication systems, ranging from representations as raindrops [32], to different aural representations (e.g. [26], [56]), or the tactile pulses used in this study and in [31]. It is unlikely that these different techniques of representation have no influence on the resulting interpretations of what they signify. So are certain features of stimuli known to influence appraisal and attribution at a perceptual level, e.g. angular and round lines [57], or characteristics of auditory stimuli, like pitch and tempo [58]. Therefor, it might be insightful to investigate whether there are systematic influences of the way in which heartbeat-signals of others are presented to receivers on the kind of inferences that they make.

Investigations could also unearth the existence of factors that might explain the observed variation in success of different sender-receiver pairs to exchange affective information through heartbeat-signals in this study.

One starting point might be the systematical investigation of the potential influence of different levels of affective intensity on a successful mediation that has been hinted at by the results of this study. Investigations in this respect might also focus on dispositions of participants themselves, e.g. their level of cardiac awareness – i.e. are receivers good heartbeat-perceivers or poor heartbeat-perceivers – , or their individual level of cardiac reactivity – i.e. are senders' hearts prone to react strongly or only mildly during emotional episodes.

2) Effects of other physiological signals

Despite exploration through a range of prototypical systems, there has been no formal investigation of the ability of other physiological reactions to convey discernible emotional meaning in the context of interpersonal interaction.

A potential hurdle for other physiological signals to convey emotional meaning might be that they cannot be rendered tangible in a way similar to how they are experienced. The beat-by-beat form of heartbeats-signals is not just an arbitrary mapping of measurements of a physiological reaction occurring alongside an emotional reaction, but represents a direct reflection of it: it can be artificially modeled in a similar way as it is experienced occurring inside the human body.

While many potential candidates for signals may be equally imbued with psychophysiological meaning, they are unlikely to possess the equivalent of this intuitive representation. An example can be seen in the activity of sweat glands in the skin that are quantified as *electrodermal activity (EDA)*. It is known as a reliable indicator for sympathetic arousal during emotional episodes [22], but does not possess an equivalent to the feeling of our heart pumping in our chest during emotional upheaval. Hence, it seems doubtful that there is a representation for it that holds the possibility for a similar intuitive understanding of its meaning. Future research on the communication of other biosignals might focus on candidates that share this connection with cardiac activity, and look for ways to shape representations in a fashion that are analogous to how they are experienced, in order to allow recipients to draw on their familiarity in an interpretation.

3) Interaction with other communication channels

Future investigations might focus on a systematic study of the effects of heartbeat-feedback when used in combination with other channels through which affective information is exchanged. Hints for possible interactions exist for example with facial expressions: findings of a study on the influence of false heartbeat-feedback on participants' interpretation of facial expressions found it to have a stronger impact on the emotional appraisal of neutral than emotional faces [59]. A special case in this area of future investigations might be the exploration of the effects of a bidirectional exchange of heartbeat-signals on participants' ability to relate to each other

VI. *Conclusion*

In this research we explored the potential of heartbeat-signals to enable the exchange of affective information in interpersonal communication. To investigate this capacity we constructed a system that enables the transmission of one person's heartbeat to a second person in the form of beat-by-beat vibrotactile representations. We then conducted an experiment in which we evaluated the capacity of recipients of this feedback to relate to the level of emotional intensity that the owners of the heartbeat-signals experienced in response to emotional stimuli.

Our findings indicate that affective information *can* be exchanged through heartbeat-feedback. This result highlights the potential that the usage of heartbeat-feedback hold for improving aspects of socio-emotional interaction, both through the enhancement of existing forms of emotional expression through technology, or through the creation of entirely new means for affective exchanges between human beings.

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References

[1] J. a Hall and M. Schmid Mast, “Sources of accuracy in the empathic accuracy paradigm.,” *Emotion*, vol. 7, no. 2, pp. 438–46, May 2007.

[2] D. Matsumoto, D. Keltner, M. N. Shiota, M. O’Sullivan, and M. Frank, “Facial expressions of emotion,” in *Handbook of emotions*, 3rd ed., M. Lewis, J. M. Haviland-Jones, and L. F. Barrett, Eds. Guilford Press, 2008, pp. 211–234.

[3] K. Scherer, “Vocal communication of emotion: A review of research paradigms,” *Speech Commun.*, vol. 40, no. 1–2, pp. 227–256, Apr. 2003.

[4] H. Wallbott, “Bodily expression of emotion,” *Eur. J. Soc. Psychol.*, vol. 28, no. 6, pp. 879–896, 1998.

[5] M. Coulson, “Attributing emotion to static body postures: Recognition accuracy, confusions, and viewpoint dependence,” *J. Nonverbal Behav.*, vol. 28, no. 2, pp. 117–140, 2004.

[6] D. Unglaub Silverthorn, *Human Physiology: An Integrated Approach*, 2nd ed. Prentice Hall, 2001.

[7] J. T. Larsen, G. G. Berntson, K. M. Poehlmann, T. A. Ito, and J. T. Cacioppo, “The psychophysiology of emotion,” in *Handbook of emotions (3rd ed.)*, 3rd ed., M. Lewis, J. M. Haviland-Jones, and F. B. Lisa, Eds. Guilford Press, 2008, pp. 180–195.

[8] J. Tooby and L. Cosmides, “The Past Explains the Present Emotional Adaptations and the Structure of Ancestral Environments,” *Ethol. Sociobiol.*, vol. 11, pp. 375–424, 1990.

[9] P. Ekman, “An argument for basic emotions,” *Cogn. Emot.*, vol. 6, no. 3–4, pp. 169–200, 1992.

[10] R. W. Levenson, “Blood, Sweat, and Fears: The Autonomic Architecture of Emotion,” *Ann. N. Y. Acad. Sci.*, vol. 1000, pp. 348–366, 2003.

[11] W. James, “What is an Emotion?,” *Mind*, vol. 9, no. 34, pp. 188–205, 1884.

[12] S. Schachter and J. Singer, “Cognitive, social, and physiological determinants of emotional state.,” *Psychol. Rev.*, vol. 69, no. 5, pp. 379–399, 1962.

[13] A. Damasio, *Descartes’ error: Emotion, reason and the human brain.* New York: Grosset/Putnam, 1994.

[14] S. H. Fairclough, “Fundamentals of physiological computing,” *Interact. Comput.*, vol. 21, no. 1–2, pp. 133–145, Jan. 2009.

[15] O. AlZoubi, M. S. Hussain, and R. A. Calvo, “Affect-Aware Assistive Technologies,” in *Assistive Technology for Cognition: A Handbook for Clinicians and Developers*, B. O’Neill and A. Gillespie, Eds. Psychology Press, 2014, pp. 47–64.

[16] J. H. Janssen, W. A. IJsselsteijn, and J. H. D. M. Westerink, “How affective technologies can influence intimate interactions and improve social connectedness,” *Int. J. Hum. Comput. Stud.*, vol. 72, no. 1, pp. 33–43, Jan. 2014.

[17] J. H. Janssen, J. N. Bailenson, W. a. IJsselsteijn, and J. H. D. M. Westerink, “Intimate Heartbeats: Opportunities for Affective Communication Technology,” *IEEE Trans. Affect. Comput.*, vol. 1, no. 2, pp. 72–80, Jul. 2010.

[18] R. Picard and J. Scheirer, “The galvactivator: A glove that senses and communicates skin conductivity,” *Proc. 9th Int. Conf. HCI*, vol. 1093, pp. 228–48, Dec. 2001.

[19] J. M. DiMicco, V. Lakshmipathy, and A. T. Fiore, “Conductive Chat: Instant Messaging With a Skin Conductivity Channel,” in *Conference on Computer Supported Cooperative Work.*, 2002.

[20] M. Hassenzahl, S. Heidecker, K. Eckoldt, S. Diefenbach, and U. Hillmann, “All You Need is Love: Current Strategies of Mediating Intimate Relationships through Technology,” *ACM Trans. Comput. Interact.*, vol. 19, no. 4, pp. 30:1–30:19, 2012.

[21] P. J. Lang, M. K. Greenwald, M. M. Bradley, and A. O. Hamm, “Looking at pictures: affective, facial, visceral, and behavioral reactions.,” *Psychophysiology*, vol. 30, no. 3, pp. 261–273, 1993.

[22] S. D. Kreibig, “Autonomic nervous system activity in emotion: a review.,” *Biol. Psychol.*, vol. 84, no. 3, pp. 394–421, Jul. 2010.

[23] L. F. Barrett, K. S. Quigley, E. Bliss-Moreau, and K. R. Aronson, “Interoceptive sensitivity and self-reports of emotional experience.,” *J. Pers. Soc. Psychol.*, vol. 87, no. 5, pp. 684–697, Nov. 2004.

[24] S. Wiens, E. S. Mezzacappa, and E. S. Katkin, “Heartbeat detection and the experience of emotions,” *Cogn. Emot.*, vol. 14, no. 3, pp. 417–427, May 2000.

[25] B. M. Herbert, O. Pollatos, H. Flor, P. Enck, and R. Schandry, “Cardiac awareness and autonomic cardiac reactivity during emotional picture viewing and mental stress.,” *Psychophysiology*, vol. 47, no. 2, pp. 342–354, Mar. 2010.

[26] J. H. Janssen, W. a. Ijsselsteijn, J. H. D. M. Westerink, P. Tacken, and G.-J. de Vries, “The Tell-Tale Heart,” *Int. J. Synth. Emot.*, vol. 4, no. 1, pp. 65–91, Jan. 2013.

[27] B. Parkinson, “Emotional effects of false automatic feedback.,” *Psychol. Bull.*, vol. 98, no. 3, pp. 471–494, 1985.

[28] S. Valins, “Cognitive effects of false heart-rate feedback.,” *J. Pers. Soc. Psychol.*, vol. 4, no. 4, pp. 400–408, Oct. 1966.

[29] B. Gaver, “Provocative awareness,” *Comput. Support. Coop. Work*, vol. 11, no. 3–4, pp. 475–493, 2002.

[30] E. Paulos, “Connexus,” in *Proceedings of the 2003 conference on Designing for user experiences*, 2003, pp. 1–4.

[31] J. Werner, R. Wettach, and E. Hornecker, “United-pulse,” in *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services*, 2008, pp. 535–538.

[32] P. Slovak, J. Janssen, and G. Fitzpatrick, “Understanding Heart Rate Sharing : Towards Unpacking Physiosocial Space,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 2012, pp. 859–868.

[33] J. Decety and P. L. Jackson, “The functional architecture of human empathy.,” *Behav. Cogn. Neurosci. Rev.*, vol. 3, no. 2, pp. 71–100, 2004.

[34] S. G. Shamay-Tsoory, J. Aharon-Peretz, and D. Perry, “Two systems for empathy: A double dissociation between emotional and cognitive empathy in inferior frontal gyrus versus ventromedial prefrontal lesions,” *Brain*, vol. 132, pp. 617–627, 2009.

[35] M. L. Hoffman, “Empathy and prosocial behavior,” in *Handbook of emotions*, 3rd ed., M. Lewis, J. M. Haviland-Jones, and L. F. Barrett, Eds. Guilford Press, 2008, pp. 440–455.

[36] A. H. Fischer and A. S. R. Manstead, “Social functions of emotion,” in *Handbook of emotions (3rd ed.)*, 3rd ed., M. Lewis, J. M. Haviland-Jones, and L. F. Barrett, Eds. New York, NY, US: Guilford Press, 2008, pp. 456–468.

[37] M. S. Clark, J. Fitness, and I. Brisette, “Understanding People’s Perceptions of Relationships Is Crucial to Understanding their Emotional Lives,” in *Blackwell Handbook of Social Psychology: Interpersonal Processes*, G. J. O. Fletcher and M. S. Clark, Eds. Malden, MA, USA: Blackwell Publishers Ltd, 2001, pp. 253–278.

[38] L. F. Barrett, L. Robin, P. R. Pietromonaco, and K. M. Eyssell, “Are Women the ‘More Emotional’ Sex? Evidence From Emotional Experiences in Social Context,” *Cogn. Emot.*, vol. 12, no. 4, pp. 555–578, 1998.

[39] J. P. Laurenceau, L. F. Barrett, and P. R. Pietromonaco, “Intimacy as an interpersonal process: the importance of self-disclosure, partner disclosure, and perceived partner responsiveness in interpersonal exchanges.,” *J. Pers. Soc. Psychol.*, vol. 74, no. 5, pp. 1238–51, May 1998.

[40] T. Lippert and K. Prager, “Daily experiences of intimacy: A study of couples,” *Pers. Relatsh.*, vol. 8, no. 3, pp. 283–298, 2001.

[41] R. el Kaliouby, R. Picard, and S. Baron-Cohen, “Affective computing and autism.,” *Ann. N. Y. Acad. Sci.*, vol. 1093, no. 1, pp. 228–48, Dec. 2006.

[42] D. Derks, A. H. Fischer, and A. E. R. Bos, “The role of emotion in computer-mediated communication: A review,” *Comput. Human Behav.*, vol. 24, no. 3, pp. 766–785, 2008.

[43] R. W. Buck, V. J. Savin, R. E. Miller, and W. F. Caul, “Communication of affect through facial expressions in humans.,” *J. Pers. Soc. Psychol.*, vol. 23, no. 3, pp. 362–371, 1972.

[44] R. Buck, R. E. Miller, and W. F. Caul, “Sex, personality, and physiological variables in the communication of

affect via facial expression," *J. Pers. Soc. Psychol.*, vol. 30, no. 4, pp. 587–596, 1974.

[45] J. Broekens and W.-P. Brinkman, "AffectButton: A method for reliable and valid affective self-report," *Int. J. Hum. Comput. Stud.*, vol. 71, no. 6, pp. 641–667, 2013.

[46] J. a. Russell, "Core affect and the psychological construction of emotion.," *Psychol. Rev.*, vol. 110, no. 1, pp. 145–172, 2003.

[47] R. Reisenzein, "Pleasure-arousal theory and the intensity of emotions.," *J. Pers. Soc. Psychol.*, vol. 67, no. 3, pp. 525–539, 1994.

[48] J. Rottenberg, R. D. Ray, and J. J. Gross, "Emotion elicitation using films," in *Handbook of emotion elicitation and assessment*, 2007, pp. 9–28.

[49] J. J. Gross and R. W. Levenson, "Emotion elicitation using films," *Cognition & Emotion*, vol. 9. pp. 87–108, 1995.

[50] A. Schaefer, F. F. Nils, X. Sanchez, and P. Philippot, "Assessing the effectiveness of a large database of emotion-eliciting films: A new tool for emotion researchers," *Cogn. Emot.*, vol. 24, no. 7, pp. 1153–1172, 2010.

[51] L. M. Jenkins and D. G. Andrewes, "A New Set of Standardised Verbal and Non-verbal Contemporary Film Stimuli for the Elicitation of Emotions," *Brain Impair.*, vol. 13, no. 02, pp. 212–227, 2012.

[52] J. Zaki, N. Bolger, and K. Ochsner, "It takes two: the interpersonal nature of empathic accuracy.," *Psychol. Sci.*, vol. 19, no. 4, pp. 399–404, Apr. 2008.

[53] I. B. Mauss, R. W. Levenson, L. McCarter, F. H. Wilhelm, and J. J. Gross, "The tie that binds? Coherence among emotion experience, behavior, and physiology.," *Emotion*, vol. 5, no. 2, pp. 175–190, 2005.

[54] S. D. Kreibig, F. H. Wilhelm, W. T. Roth, and J. J. Gross, "Cardiovascular, electrodermal, and respiratory response patterns to fear- and sadness-inducing films," *Psychophysiology*, vol. 44, no. 5, pp. 787–806, 2007.

[55] D. H. Jacobs, J. Shuren, D. Bowers, and K. M. Heilman, "Emotional facial imagery, perception, and expression in Parkinson's disease.," *Neurology*, vol. 45, no. 9, pp. 1696–1702, 1995.

[56] B. Parkinson and a. S. Manstead, "An examination of the roles played by meaning of feedback and attention to feedback in the 'Valins effect.,'" *J. Pers. Soc. Psychol.*, vol. 40, no. 2, pp. 239–245, 1981.

[57] J. Aronoff, "How We Recognize Angry and Happy Emotion in People, Places, and Things," *Cross-Cultural Res.*, vol. 40, no. 1, pp. 83–105, 2006.

[58] K. R. Scherer and J. S. Oshinsky, "Cue utilization in emotion attribution from auditory stimuli," *Motiv. Emot.*, vol. 1, no. 4, pp. 331–346, 1977.

[59] M. a Gray, N. a Harrison, S. Wiens, and H. D. Critchley, "Modulation of emotional appraisal by false physiological feedback during fMRI.," *PLoS One*, vol. 2, no. 6, p. e546, Jan. 2007.