Intimate Heartbeats: Opportunities for Affective Communication Technology

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Abstract—Despite a variety of new communication technologies, loneliness is prevalent in Western countries. Boosting emotional communication through intimate connections has the potential to reduce loneliness. New technologies might exploit biosignals as intimate emotional cues because of their strong relationship to emotions. Through two studies, we investigate the possibilities of heartbeat communication as an intimate cue. In the first study ($N = 32$), we demonstrate, using self-report and behavioral tracking in an immersive virtual environment, that heartbeat perception influences social behavior in a similar manner as traditional intimate signals such as gaze and interpersonal distance. In the second study ($N = 34$), we demonstrate that a sound of the heartbeat is not sufficient to cause the effect; the stimulus must be attributed to the conversational partner in order to have influence. Together, these results show that heartbeat communication is a promising way to increase intimacy. Implications and possibilities for applications are discussed.

Index Terms—Psychology, social issues, artificial, augmented, and virtual realities, communications applications, nonverbal signals.

1 Introduction

Closeness and intimacy with others are essential for our health and well-being [1], [2]. As humans evolved, they have always depended on the advantages of living and working close together [3]. Our need to belong is such a profound motivation that loneliness reduces happiness [4], [5], increases our chances of depression [6], and even influences our physical health [7], [8]. For instance, married individuals are known to have a higher survival chance of cancer than singles [9]. Moreover, separation from one's partner may lead to strong negative effects, sleeping problems, subjective stress, and physical symptoms [10].

Some scholars argue that over the last decades, individualism and loneliness have significantly increased in Western countries [1]. For instance, respondents in 2004 were three times more likely to report having no one with whom to discuss important matters than respondents in 1985 [11]. This has sparked an interest in research on systems and technologies that can improve our sense of belongingness and reduce our feeling of loneliness, such as awareness systems [12] and connectedness devices [13], [14]. Research on these systems has mainly focused on improving the connection by trying to get people to interact more and share more personal information. For example, Vetere et al. [15] implemented the Hug Over a Distance. The Hug Over a Distance enables tactile communication similar to giving someone a hug. Other examples of awareness systems include the Cube and the Picture Frame by Garnæs et al. [16]. The Cube is a virtual three-dimensional cube on which intimate couples can place symbols for the other to see. The authors argue that combining several symbols can create complex and expressive messages. The Picture Frame provides a way of dynamically adding graphical symbols to shared photos. After the selection of a symbol, it appears as a thought bubble on the other person's Photo Frame. Other work on awareness systems can, for instance, be found in [17], [18]. For a recent overview, see Markopoulos et al. [12].

Converging evidence shows that one of the essential elements for improving a sense of connectedness or intimacy is the communication of emotions. Diary studies of adolescents and married couples have consistently shown that emotional self-disclosures have a stronger impact on intimacy than factual self-disclosures [19], [20]. In line with this, Butler et al. [21] have shown that emotional suppression decreases one's chances of forming new relationships. Moreover, automatic mimicking of other's emotions improves liking of and attraction to the mimicker as it is a sign of validation [22], [23]. In addition, partners' emotional convergence leads to increased relationship quality [24]. Furthermore, increased emotion recognition accuracy between partners will also lead to increased marital satisfaction and relationship quality [25]. Finally, the negative effects of separation from one's loved ones can be ameliorated by sharing affective experiences to become more emotionally in touch [10]. Taken together, the affective nature of intimacy is found in the important role emotions

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play in intimacy development and the strong influence of intimacy of our affective state (e.g., [10]).

Because emotions play such a central role in closeness and intimacy, it is important to look at potential ways of improving and expanding the range of signals through which we communicate our feelings when interacting from remote physical locations. Currently, communication of emotions relies heavily on facial and vocal expressions [26], [27]. However, these signals are absent in many new communication applications. For example, in online chatting, we rely on emotional representations called emoticons [28]. There is compelling evidence that computer-mediated communication (CMC) need not be less intimate than face-to-face (F2F) interaction (e.g., [29], [30]). Walther [31] even argues in his *hyperpersonal communication theory* that communication in CMC can be more intimate than in F2F because of increased control and increased self-disclosure due to a reduction of nonverbal signals. Because communication of emotion through artificial means can be just as powerful as F2F communication, it might be valuable to look at other emotional signals that can be tracked and communicated by technologies and that can possibly serve as intimate cues. One such a potential intimate emotional communication mechanism might be the sharing of heartbeat information between individuals.

Evidence for the possible effects of heartbeat sharing comes from studies investigating the perception of one's own heartbeat [32], [33], [34], [35]. One of the first heartbeat perception studies was done by Valins [36] and gave participants false feedback on their own heart rate. The results showed that the false heart rate feedback influenced participants' perceptions of their own emotional state (see [37] for a review). Furthermore, there is ample evidence that cardiac awareness (i.e., how well individuals can perceive their own heartbeats) is associated with the intensity of emotional experience (e.g., [38], [39], [40], [41]). Often, heartbeat perception tasks are used to measure cardiac awareness and relate this to emotional experience [42]. For instance, Wiens et al. [43] reported that good heartbeat perceivers reported more intense emotions to film stimuli than poor heartbeat perceivers. Taken together, this shows that heartbeat perception is related to emotional experience. Nonetheless, it is important to note that these studies are concerned with the awareness and presentation of *one's own* heartbeat. We are not aware of any studies that have investigated the interpersonal communication of heartbeats that we focus on in this work.

Because heartbeat perception affects emotion perception and because the communication of emotions increases intimacy, we expect that perceiving someone else's heartbeat will be experienced as an intimate nonverbal cue. Applications for such heartbeat communication have been suggested before [44], but have not been empirically evaluated. Hence, this paper investigates the power of heartbeat communication as an intimate nonverbal cue.

The systematic study of cues that signal nonverbal intimacy started about four decades ago with the seminal work of Argyle and Dean [45] and Mehrabian [46]. They showed that people compensate for inappropriate increases in intimacy. For instance, when stepping into an elevator with a group of people, interpersonal distance might suddenly be inappropriately close. As a consequence, people might look at the walls, floor, or ceiling instead of at each other, reduce their smiling, and turn sideways or away from each other. These effects have been replicated many times [47], [48], providing a good behavioral paradigm for investigating the intimacy of other nonverbal cues.

To investigate the effects of heartbeat communication, we implemented a dual approach. First, we examined self-reported intimacy ratings during situations that differed in interpersonal distance, mutual gaze, and heartbeat communication. Consequently, we compared the strength of the known effects of interpersonal distance and mutual gaze on intimacy with that of the new effect of heartbeat communication. Second, to bolster the self-report measures, we investigated if the new heartbeat cue interacts with traditional nonverbal cues. We chose the relationship between interpersonal distance and heartbeat, as interpersonal distance tends to increase in the presence of other intimate nonverbal behavior as a compensation mechanism [45], [48], [49]. Specifically, we examined whether or not the presence of heartbeat communication would cause participants to adjust their interpersonal distance.

We examined these effects in an Immersive Virtual Environment (IVE). Such environments are methodological tools that have been used to investigate social psychological effects [50], [51], including interpersonal distance [52] and gaze behaviors [49]. The use of IVEs allows us to control a confederate's displayed behavior, which might otherwise cause confounds in the research paradigm. Furthermore, it gives us a very precise measurement of the interpersonal distance at the level of millimeters between the interactants, as the IVE employs accurate location tracking equipment.

2 Experiment 1

In the first experiment, we tested the effects of the sound of a human heartbeat on self-reported intimacy and interpersonal distance. In this study, we manipulated distance, gaze, and heartbeat communication between a participant and a confederate. We hypothesized that self-reported intimacy would be higher with low interpersonal distance compared to high distance, with mutual gaze instead of averted gaze, and when perceiving the other's heartbeat as opposed to silence. Furthermore, we expected that if heartbeat sound was experienced as an intimate nonverbal cue, participants would keep a larger interpersonal distance to someone else when hearing the other's heartbeat as a compensation for the perceived increase in intimacy. Hence, we compared the interpersonal distance interactants kept while hearing the other's heartbeat to the distance kept during silence.

2.1 Experimental Setup

2.1.1 Participants and Design

Participants were 16 men and 16 women (age: $M = 25.3$, $SD = 11.9$) who received 15 USD for participation. The experiment was run in two phases. For the first part of the experiment, participants were assigned to a 2 (sound: heartbeat/silence) $\times$ 2 (gaze: eyes/chin) $\times$ 2 (interpersonal distance: 3 ft/9 ft) design, with repeated measures on all

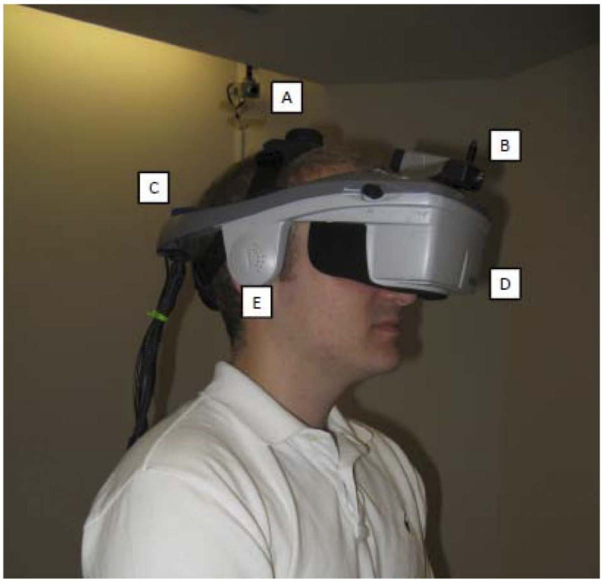

Fig. 1. The setup of the IVE used in the study. Cameras in the corners (A) of the room track the location of an infrared light (B). Accelerometers (C) located at the back of the HMD track the yaw, pitch, and roll of the head. This information is processed by a computer that renders the virtual image on the stereoscopic display of the HMD (D) and the sound through the headphones (E).

factors. For this, the participants were evenly divided over eight digram balanced orders, i.e., the eight conditions appeared in each serial order the same number of instances, and each condition was equally often preceded by each of the seven other conditions. For the second part of the experiment, the participants were randomly assigned to one of the two conditions of sound (heartbeat/silence).

2.1.2 Materials and Confederates

Participants were placed in a fully immersive virtual environment. For this, they wore a head mounted display (HMD) equipped with sensors to track their location and head movements. This way, the stereoscopic image of the environment could be updated constantly according to the participant's movements. Detailed equipment specifications can be found in Yee and Bailenson [53]; see also Fig. 1.

During the experiment, the participants were put in a virtual room together with a same-sex confederate. The confederates were unknown to the participants. The confederates' faces had been photographed to construct a 3D image of their face. In order to ensure that the confederate faces were of roughly the same attractiveness, we ran a pretest. Twenty volunteers rated these two faces, together with 12 other faces, for attractiveness on a seven-point scale with the following labels: extremely unattractive, moderately unattractive, slightly unattractive, average, slightly attractive, moderately attractive, and extremely attractive. Paired samples t-tests confirmed that the confederates' faces did not differ in attractiveness from one another ($p > 10$; $M_{male} = 3.25$, $M_{female} = 3.75$).

The heartbeat sound was preconstructed and resembled the sound of listening to one's heart through a stethoscope. The sound consisted of loops of 18 consecutive heartbeats. Pilot testing indicated that no one recognized the repetition in the sound. Moreover, none of the participants suspected the sound to be synthetic. The sound displayed an average heart rate of 69.7 beats per minute (bpm). This was in line with studies reporting average heart rates around 70 bpm during seated interpersonal communication [48]. Natural fluctuation in the interbeat intervals had a standard deviation of 2.3 bpm with a minimum of 65.4 bpm and a maximum of 72.8 bpm.

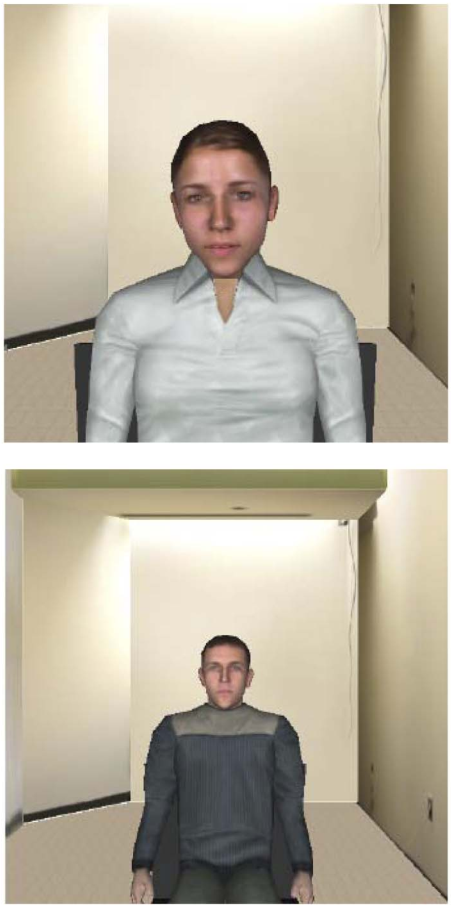

Fig. 2. Participant view of the female confederate in the 3 ft interpersonal distance condition and of the male confederate in the 9 ft interpersonal distance condition.

2.1.3 Procedure

Upon arrival, participants signed an informed consent form and filled out a biographical questionnaire. Next, they were taken to an adjacent room, where they were introduced to a same-sex confederate. The experimenter explained that both the participant and the confederate would be wearing a virtual reality helmet and, although sitting in different physical rooms, would be in the same virtual room. Subsequently, the participant was taken back to the experimentation room and put on the HMD. After the participant got acquainted with the equipment, the experimenter told the participant that he would check if the other person was ready to be put in the virtual room with the participant. When the experimenter returned and started the experiment, the participants saw a prerecorded computer image of the confederate sitting opposite them (see Fig. 2).

Participants were now instructed that the first part of the experiment would consist of eight trials. Each trial started with a minute of rest to create separation between trials. Instructions on the screen would then ask the participant to look either at the eyes or the chin of the confederate during the next 30-second trial. This was reciprocated by the confederate by slightly tilting the confederate's head downward when the gaze was at the chin. In addition, the participant was instructed that the distance to the other person differed over trials and that in some trials they would be hearing the other's heartbeat. The heartbeat sound was prerecorded and the same over all conditions. The sound was presented through the headphones integrated in the HMD. After the eight trials, participants were put back in each trial for 10 seconds and answered two questions based on the often employed Inclusion of Other in Self-Scale (IOS) [54]: "Which image best describes the situation during the previous trial?" and "Which image best describes how intimate you felt toward the other person during the previous trial?" Answers were given verbally on the same pictorial scale as the IOS. After the eight trials finished, the participants filled out a six-item social presence questionnaire, as previous studies demonstrated the importance of taking social presence into account [52]. In the current study, it did not affect our analyses so it is not reported further. The participants also filled out manipulation check questions asking them if they sometimes heard the other's heartbeat and at other times didn't, sometimes were in closer proximity to the other than at other times, and sometimes saw the other looking at their eyes whereas at other times saw the other looking at their chin. All participants reported yes to the former two questions. Five participants did not note the change in the gaze direction of the confederate. The inclusion of their data did not change our results and the data were kept in the final data set for analyses.

During the second part of the experiment, participants stood up from their chairs wearing the HMD to get acquainted with walking around in the virtual room. Next, they were put back in their original starting position. The experimenter instructed them that the other person would be standing opposite them. The participant was asked to walk up to the other to as close as was comfortable for them and wait there for 30 seconds. We introduced this 30-second period to discourage participants from moving uncomfortably close to the confederate. Half of the participants heard the heartbeat sound during this part and the other half did not. Measurements were successful for 22 of the participants, as the tracking data were lost for the first 10 participants due to technical difficulties.

Finally, the participants read a debriefing form and received their payment. The experiment took approximately 45 minutes.

2.2 Results and Discussion

2.2.1 Intimacy Reports

The two items of the IOS self-report scale were averaged (Cronbach's $\alpha = 91$). Resulting scores were submitted to a 2 (sound: heartbeat/silence) $\times$ 2 (gaze: eyes/chin) $\times$ 2 (distance: 3 ft/9 ft) $\times$ 2 (sex: male/female) repeated measures ANOVA. Univariate tests showed the main effects for sound ($F(1,30) = 49.2, p < 0.001$, partial $\eta^2 = 0.62$), gaze ($F(1,30) = 20.9$, $p < 0.001$, partial $\eta^2 = 0.41$), and distance ($F(1,30) = 43.9$, $p < 0.001$, partial $\eta^2 = 0.59$). The interactions between the three different cues were not significant: sound $\times$ distance ($F(1,30) = 0.42$, $p = 0.52$, partial $\eta^2 = 0.01$), sound $\times$ gaze ($F(1,30) = 3.10$, $p = 0.09$, partial $\eta^2 = 0.09$), distance $\times$ gaze ($F(1,30) = 0.22$, $p = 0.65$, partial $\eta^2 = 0.01$), and sound $\times$ distance $\times$ gaze ($F(1,30) = 0.92$, $p = 0.35$, partial $\eta^2 = 0.03$). Means and SEs are depicted in Fig. 3.

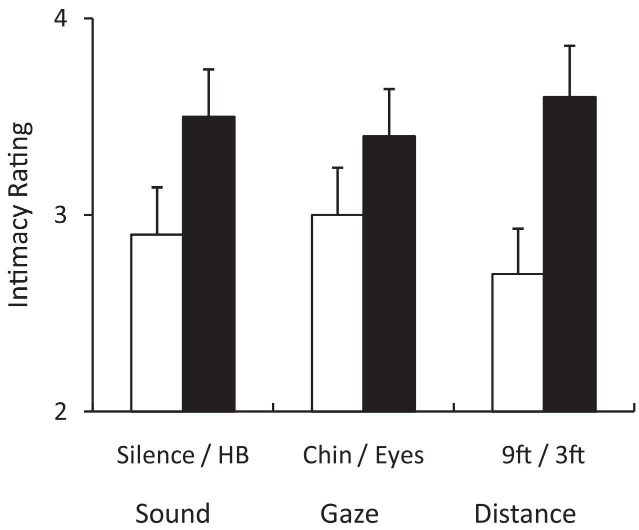

Fig. 3. Intimacy ratings for sound (silence/heartbeat), gaze (chin/eyes), and interpersonal distance (9 ft/3 ft). The error bars depict 1 SE.

These results show that self-reported intimacy is higher when hearing someone's heartbeat compared to silence. Furthermore, the found effect size is similar to the well-established effects of interpersonal distance and gaze [48], which strengthens our hypothesis that heartbeat communication has a strong effect on intimacy.

2.2.2 Kept Distance

The distance between the participant and the confederate was averaged over the first 10 seconds that the participants stood still after walking up to the confederate. This distance measure was submitted to an independent samples t-test with sound (heartbeat/silence) as an independent variable. Results showed an effect of sound ($t(20) = 3.0$, $p < 0.007$, Cohen's $d = 1.32$). More interpersonal distance was kept when hearing the confederate's heartbeat ($M = 0.85$ m, $SE = 0.10$) than when in the silent condition ($M = 0.46$ m, $SE = 0.07$). Such an increase in interpersonal distance can typically be observed in situations where participants want to compensate for an increase in intimacy, and therefore confirms the findings of the self-reports that heartbeat is an intimate cue.

To test the relation between self-reported intimacy and kept interpersonal distance, we first averaged all intimacy ratings of each participant as obtained in the first part of the experiment. Subsequently, between-subject Pearson correlations of kept interpersonal distance as measured in the second part, with the average intimacy rating of each participant, show a significant correlation ($r(21) = 0.42$, $p < 0.05$). This finding further confirms the relation between interpersonal distance and experienced intimacy, and possibly alleviates some of the concerns one might have with the within-subject nature of the self-reports.

3 Experiment 2

In Experiment 2, we further elaborated the findings of the first experiment by separating out the effects of the heartbeat sound itself and the meaning of the sound (i.e., attributing that sound to a specific person). We expected that merely hearing a heartbeat sound would not change the interpersonal distance participants kept, but it was the idea that it was the confederate's heartbeat that would make the participant compensate for their kept interpersonal distance.

3.1 Experimental Setup

3.1.1 Participants and Materials

Participants were 17 women and 15 men (age: $\mathrm{M} = 22.8$, $\mathrm{SD} = 5.5$) who received 10 USD for participation. The participants were randomly assigned to one of three conditions of heartbeat communication: silence, artificial heartbeat, and real heartbeat. The silence and real heartbeat conditions were the same as in Experiment 1. In the artificial heartbeat condition, the same sound was displayed to the participants as in the real heartbeat condition, but they were told that it was an artificially constructed sound that we had downloaded from the Internet. Experiments were conducted with the same materials as Experiment 1. Confederates were different from the ones in the first experiment to show that the effect was independent of the confederates.

3.1.2 Procedure

Upon arrival, participants signed an informed consent and filled out a demographics questionnaire. Subsequently, they were taken to an adjacent room in which they were introduced to the same-sex confederate. The experimenter explained that both the participant and the confederate would be wearing a virtual reality helmet and, although in different physical rooms, would be in the same virtual room. Furthermore, the experimenter pointed out to the participants in the real heartbeat condition that the confederate would be wearing sensors that would measure his heart rate and that the participant would be able to hear this heart rate when in the virtual environment. When telling this, the confederate showed the participant a set of ECG sensors.

Subsequently, the participant was taken back to the experimentation room and put on the HMD. After the participant got acquainted with the equipment, the experimenter told the participant that he would check if the other person was ready to be put in the virtual room with the participant. When the experimenter returned and started the experiment, the participants saw a prerecorded computer image of the confederate standing opposite them. In the artificial heartbeat condition, the experimenter told the participants that he would start a sound that the participant might recognize as the sound of a heartbeat used in movies or games. The experimenter went on to say that this was a prerecorded sound downloaded from the Internet. In the real heartbeat condition, the experimenter told the participants that he would now check if the connection with the heartbeat signal was working and that the participant would be hearing the other's heartbeat. He then started the same prerecorded sound as in the artificial heartbeat condition. No sound was displayed to the participants in the silence condition.

To give the participants some exposure to the stimulus and make them feel more comfortable with their new environment, they were told to look at the other's eyes while the experimenter would make some calibrations to the system. After 60 seconds, the experimenter told the participants to walk up to the other to as close as comfortable for them. They were instructed that they would have to stand there for 30 seconds. After the participants confirmed understanding of the instructions, they walked up to the confederate and waited there for 30 seconds. After 30 seconds, the experimenter told them to take off the HMD and fill out the same presence questionnaire used in Experiment 1, and two open-ended questions: "What did you hear when you were in the virtual environment?" and "What do you think this experiment is about?" Finally, participants were debriefed and paid.

3.2 Results

We averaged the kept distance during the 30 seconds the participants were standing close to the confederate. Simple contrasts compared the silence and artificial heartbeat conditions to the real heartbeat condition to test our hypotheses based on Experiment 1 that a real heartbeat would lead to a larger kept distance (than silence or an artificial heartbeat). Kept distance was larger in the real heartbeat ($\mathrm{M} = 82$ cm) condition than in the silence ($\mathrm{M} = 57$ cm, $p < 0.05$, Cohen's $d = 0.9$) and artificial heartbeat conditions ($\mathrm{M} = 56$ cm, $p < 0.05$, Cohen's $d = 1.0$). Means and SEs are depicted in Fig. 4. Subsequently, we submitted kept distance to an ANOVA with heartbeat communication (silence/artificial heartbeat/real heartbeat) and sex (male/female) as between-subject factors. The results showed an effect of heartbeat communication ($F(2, 34) = 3.35$, $p < 0.05$, partial $\eta^2 = 0.19$), but not of sex ($F(1, 34) = 2.34$, $p < 0.14$, partial $\eta^2 = 0.08$) or heartbeat communication $\times$ sex ($F(2, 34) = 1.23$, $p = 0.31$, partial $\eta^2 = 0.08$). Finally, an ANOVA of heartbeat communication on presence ratings showed no significant effect ($F(2, 32) = 0.91$, $p = 0.41$, partial $\eta^2 = 0.06$).

4 Discussion

In this paper, we investigate the effects of heartbeat on intimacy. In two experiments, we manipulated heartbeat communication, measured self-reported intimacy, and kept interpersonal distance as a behavioral measure of intimacy. We expected that, in the conditions in which participants thought they were hearing the confederate's heartbeat, self-reported intimacy and kept interpersonal distance would be higher.

Manipulation checks confirmed that the manipulation was successful. In the first study, everybody said that they perceived differences in personal distances and sound. Some people reported not seeing a clear difference between the two gaze conditions, which might explain the somewhat lower effect size for gaze compared to interpersonal distance and heartbeat sound. In the second study, participants' responses when asked what they heard during the experiment were congruent with the condition they were in. Finally, both experiments confirmed that the effects of the heartbeat sound were not due to increases in social presence.

The results confirmed our hypothesis. In the first experiment, there is a large effect of sound on self-reported intimacy. In addition, this effect was similar in size to that of interpersonal distance and larger than the effect of gaze. This comparison is important as interpersonal distance and gaze are nonverbal cues that have been studied widely and are uncontroversial as cues to intimacy [48]. The fact that heartbeat sound has similar or stronger effects than these

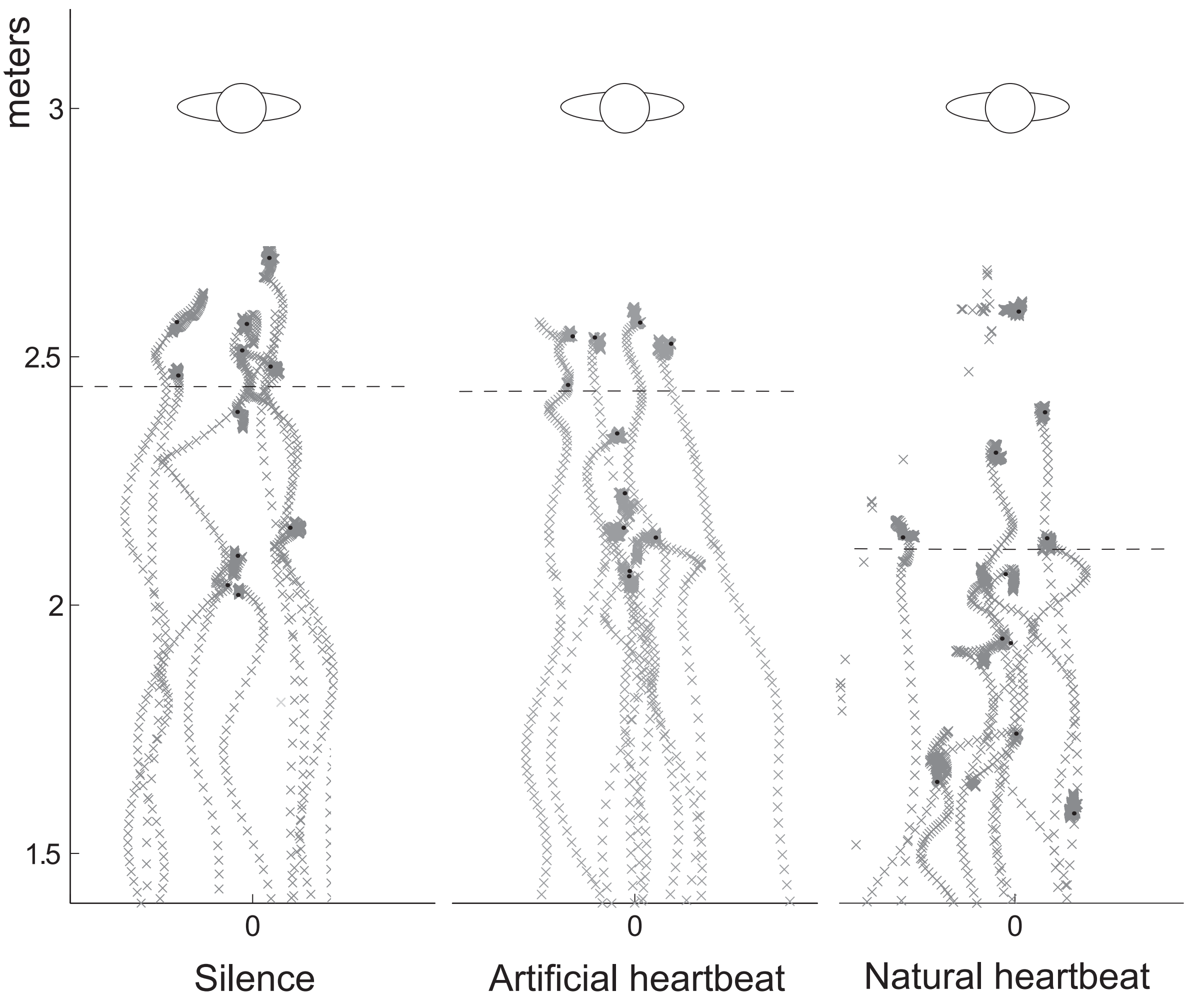

Fig. 4. Bird's eye view of (the end of) the paths the individual participants took for each of the three conditions of cardiac communication. Gray crosses depict the path sampled at 15 Hz. Black dots represent the end point of each participant. The beginning position was at [0, 0] for each participant. The dotted lines depict the mean of each of the three conditions. The figure at the top shows the position of the virtual confederate. Distances are depicted in meters.

traditional nonverbal cues strengthens our belief that heartbeat has a very strong effect on intimacy as well. To test if this effect also had effects on behavior, we compared kept distance when hearing a heartbeat sound or silence. Kept distance was almost twice as large when hearing a heartbeat sound than when hearing silence. Taken together, these findings show that heartbeat communication is similar to other nonverbal behavior cues in its effects on both experience and behavior.

To further confirm that these effects were not merely due to hearing the sound of a heartbeat, we ran a second experiment. The results of this experiment further confirmed the fact that heartbeat can be perceived as an intimate cue. Although the exact same sound was used in all cases where participants heard a heartbeat sound, when the participants thought that they were hearing a representation of the confederate's heartbeat, they kept a larger distance from this confederate compared to hearing an unrelated sound downloaded from the Internet or silence. The effect sizes and means of experiments 1 and 2 were similar for the same conditions. Hence, the effects in experiment 2 are not due to merely hearing the sound but because the sound was associated with the confederate.

Because of the within-subject nature of experiment 1, there might have been a confirmation bias in the self-reported intimacy. We have tried to alleviate this concern by showing a significant between-subject correlation of self-reported intimacy with kept interpersonal distance. Nonetheless, for future work, it might be interesting to include self-reported and other behavioral measures (e.g., gaze) in a between-subject design to further investigate heartbeat communication effects.

One of the limitations of the current study is that the effects might have been caused by the novelty of the heartbeat sound. We have tried to reduce this possible effect by taking a quite well-known and often auditory represented signal. Moreover, we have parsed out the effects of the actual stimulus with the meaning of the stimulus. Nonetheless, compared to other nonverbal behavior, the perception of someone else's heartbeat is rather uncommon. Hence, as a direction for future studies, it might be interesting to see if these effects persist when people are subjected to repeated exposure to heartbeat sounds. Furthermore, it could be interesting to compare other modalities such as the visual or haptic domain to see if less common representations of the heartbeat signal lead to similar effects.

We chose to use the heartbeat signal for its familiarity. There exist common representations of heartbeat, like the sound we used, so it could be easily recognized. Additionally, heart rate is probably easily associated with emotions because of the folk psychology surrounding it. Nonetheless, besides heartbeat, the representation of other physiological signals may also be suitable as intimate cues. Other physiological signals such as skin conductance, respiration, or skin temperature are also influenced by emotions. Hence, the same reasoning of heartbeat communication as an intimate cue can be applied to other signals. With clear instructions or experiences, people could learn to interpret these signals as intimate emotional cues as well. Future research could focus on finding representations of other physiological signals to see if they are also useful as intimate emotional cues.

Future research could also be directed at investigating possible mechanisms through which the effects of heartbeat communication arise. The effects we found could, for instance, be due to attentional differences between the conditions, which have been shown to affect one's own heartbeat perception [55]. They could also be mediated by heartbeat entrainment [56], in which one's own heartbeat shifts toward the perceived rhythm. Such changes in heartbeat could in turn change one's experience. Hence, future research should incorporate measures of such possible mediating factors to clarify what the active ingredients are that make heartbeat communication an intimate experience.

4.1 Implications and Applications

A lot of research has focused on the role of biosignals in emotions [57], [58]. Converging evidence has shown that biosignals, and especially cardiac activity, play a central role in our own emotional experience [36]. This knowledge has been employed in affective computing research, where biosignals are often used as indicators of emotion [59], [60]. Many studies have tried to predict emotional state from biosignals or have included biosignals in specific applications that deal with emotions [61], [62].

Although biosignals are often employed in these human-computer interactions, this is one of the first studies that shows the potential of biosignals in human-human interaction. We have shown that heartbeats are experienced as intimate cues. Because heartbeat communication is an intimate experience, it could potentially help establish and maintain closer connections between individuals, as sharing intimate information improves closeness. This is an important mechanism, especially in a society in which individualism and loneliness are becoming more and more prevalent [1]. Sharing heartbeats between partners might help to reduce the impact being away from one's loved ones has on health and well-being. Future research is necessary to further clarify the long-term effects of heartbeat communication on social connectedness and loneliness.

Our work shows that the effects of heartbeat communication are susceptible to compensatory mechanisms, as suggested by Argyle and Dean [45]. On the one hand, this might render practical application of heartbeat communication less useful because intimacy effects can be compensated by reducing intimacy in other channels. On the other hand, such compensatory changes are most likely to happen only in cases where intimacy is experienced as too high, which is also the case with traditional nonverbal signals. However, traditional nonverbal behavior allows conscious control over what is displayed. Hence, one has the power to influence the intimacy equilibrium through changing one's nonverbal display. Therefore, to make heartbeat communication useful in practice, it is probably necessary that users can control the display of their biosignals. In this sense, we can learn from experiences in the domain of awareness systems, where the privacy considerations surrounding automatic capture, processing, and display of personal information have been a topic of study over recent years [12]. Taken together with the right technological implementation, it might be possible for heartbeat communication to adhere to established communication dynamics and function as any other nonverbal signal.

In addition, taking the central role that heartbeat plays in individuals' emotions opens up a window of other opportunities for the role of heartbeats in communication in more general terms. For instance, communicating heartbeat information could improve emotion recognition, which is a central aspect of social interaction [63]. By sharing heartbeat information in situations where other emotional cues are lacking (like chat rooms), people are likely to understand each other better. Furthermore, in face-to-face settings it is often problematic to correctly infer emotional state as well [64]. Hence, in these settings, adding extra emotional information might be very beneficial. This might be especially beneficial for people who have otherwise great difficulty in recognizing emotions, like autistic individuals. Cardiac communication could also play a central role in decision making, as our emotions are essential to making fast decisions [32]. These often depend on the people around us and the emotions they display. Biosignal communication could enhance this decision-making process by making emotions clearer and easier to communicate.

Applications of biosignal communication can benefit from recent work on wearable technologies. Recently, a lot of work has been done on physiological sensors. Unobtrusive wireless measurement of heart rate and other physiological signals is available through several measurement platforms [65], [66]. For applications of biosignal communication, it is also important to have unobtrusive actuators. These actuators will be domain dependent. If a mobile solution is necessary, haptic representation of the heartbeat might be a good solution as it can be integrated in existing devices that are worn on the body and does not interfere with other perceptual modalities. In any case, more research is necessary to see what kind of representations work well for the communication of biosignals. Future research could, for instance, employ wearable technologies to track and display heartbeats in more ecologically valid settings and over a longer time span. Such research is necessary to establish the potential beneficial effects of heartbeat communication on social connectedness, health, and well-being.

4.2 Conclusion

In this age of the Internet in which people interact more and more with their computers and less and less with each other, we need new ways to communicate emotions and maintain close connections. Decades of research have shown the importance of physiological signals for our own emotional experiences. This study presents evidence that physiological signals can be important communicative tools as well. Heartbeats are shown to be a powerful intimate nonverbal cue. Because of the intimate nature of heartbeat communication, it could potentially prove to be beneficial for social connectedness. Similarly, heartbeat communication might also improve emotion recognition and communication. This opens up a future in which we augment our natural emotion communication by new technologies that share the biosignals carrying our emotions.

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