Can You Hear My Heartbeat?: Hearing an Expressive Biosignal Elicits Empathy

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ABSTRACT

Interfaces designed to elicit empathy provide an opportunity for HCI with important pro-social outcomes. Recent research has demonstrated that perceiving expressive biosignals can facilitate emotional understanding and connection with others, but this work has been largely limited to visual approaches. We propose that hearing these signals will also elicit empathy, and test this hypothesis with sounding heartbeats. In a lab-based within-subjects study, participants (N = 27) completed an emotion recognition task in different heartbeat conditions. We found that hearing heartbeats changed participants' emotional perspective and increased their reported ability to "feel what the other was feeling." From these results, we argue that auditory heartbeats are well-suited as an empathic intervention, and might be particularly useful for certain groups and use-contexts because of its musical and non-visual nature. This work establishes a baseline for empathic auditory interfaces, and offers a method to evaluate the effects of future designs.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in collaborative and social computing**; *Auditory feedback*; • **Applied computing** → *Sound and music computing*.

KEYWORDS

empathy, emotion, sound, music, rhythm, physiology, heart rate, communication, affect, AAC, ASD

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1 INTRODUCTION & MOTIVATION

Empathy is a fundamental socio-affective process entailing the ability for a person to understand and "feel-into" another person's emotions, or to experience something from the other person's point of view [20, 83, 93]. Empathy provides an important evolutionary function as it enables humans to be cooperative, understanding, caring, sympathetic and altruistic [27]. It is also deeply embedded in the need for human communication and our ability to listen to each other [12]. Understanding the factors that influence empathic state allows HCI researchers to design technologies that augment or elicit empathy between two or more people (i.e. "empathic technologies" [50]). These technologies may help to make mediated communication more empathic and support positive social change [66].

As human communication technologies have become more complex, developing systems that support affective intelligence has remained a central goal [80]. The advent of wearable technologies have enabled the sharing of social signals of affect directly from the autonomic nervous system [14]. Unlike externalized emotional expressions such as facial expressions or tone of voice, these signals are not directly observable and some degree of mediation is required. HCI researchers have begun to explore the effects of perceiving these signals and have found that they promote positive interpersonal and empathic qualities [24, 48, 66].

One of the most prominent signals of affect is the rhythm of the heart, which varies continuously with physiological arousal [81]. An individual's ability to perceive their own heartbeat (i.e. "interoception") is predictive of the intensity of their felt emotions [7, 103] and empathic responding [41]. Although common experiences of the heartbeat are auditory and tactile, to date, the majority of research on heartrate sharing has used visual methods such as graphs [66], visualizations [65] and text [42]. A plethora of research indicates that tempo is a salient acoustic cue of arousal [36] that allows listeners to "recognize" and "feel" emotions in music [88]. Perhaps a similar mechanism could enable listeners of auditory heartbeats to recognize and feel the emotional state of another person, facilitating empathy with that person's experience. If so, this auditory intervention could be applied in new empathic technologies as a complement or alternative to visual methods.

To this end, we explore the empathic effects of auditory heartbeats, a rhythmic auditory signal resembling a musical beat. Prior work in HCI has advocated for research into empathic technologies [50], and sharing physiological signals—especially heartrate—may support this goal [42, 48, 51, 66]. To this literature, we contribute a controlled lab-study demonstrating the capacity of auditory heartbeats and their tempo to affect user's emotional perspective and convergence with the affect of another person. Our evaluation strategy may be useful for others seeking to compare the empathic

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effects of different approaches to physiological signal sharing or empathic interventions.

2 RELATED WORK

Although empathic communication technologies have been around arguably since the beginning of humankind, recent research has formalized its application in the design of interactive systems [50]. Empathic technologies mediate human-human interactions to assist or augment human's natural empathic abilities. The field leverages insights and methods from Affective Computing [80] and Social Signal Processing [98], but focuses on human-human social interaction as opposed to human-machine. The field is organized around core concepts arising from the psychology and neuroscience of empathy [28].

2.1 Expressive Biosignals as Empathy Generators

Although affective expression is usually shared through observable behaviors such as facial expressions, gestures, speech and language, new technologies allow sharing of internal, physiological signals arising from the autonomic nervous system [16]. These signals reflect unconscious and automatic processes that vary with arousal and accompany affective state [57, 82]. Unlike voluntary expressions of affect arising from the somatic nervous system, these expressions of the autonomic nervous system are not easy to control or fake.

Recent work has begun to explore these signals as affective communication channels mediating human-to-human interactions. Common signals have included skin conductance [17, 24, 46], breath [34, 72], heartrate [64, 65], EEG [63] and combinations [104]. Because these signals are internal and not usually perceived by others, a variety of questions have arisen as to how to best represent them. However, a consistent finding is that their perception affects emotional perception and connection with others [24, 42, 48, 62, 66]—core components of empathy.

Within this body of work, the heart has been a particularly prominent signal for studying the effects of physiological signal sharing [22, 23, 42, 64, 65, 70, 102]. However, there are also many reasons to focus on the heart. The heart is a reliable physiological signal of affect through the dynamics of its rhythm (e.g. the heartrate, heart-rate variability [81]). The prevalence of smart-watches and other wearables have increased access to the heart via physiological signals. Further, the heart is already an important cultural locus of feeling [56], and is salient in the perception of our own physiology (e.g. "interoception" [21]). The importance of this signal is evident by the fact that representations of the heart are already embedded in communication technologies (e.g. "heart" emoji, and Apple's *Digital Touch* [3]).

Previous studies have shown that sharing the heartrate signal positively affects interpersonal interactions by increasing intimacy and feelings of connectedness [48, 51, 94, 102], and altering emotional perspective [66, 70]. These types of interpersonal and emotional effects have been defined in two broad categories [94]: heartrate as information, and heartrate as connection. When heartrate is understood as information, it carries information about a person's physiological state. By contrast, in when heartrate is perceived as connection, it promotes feelings of interpersonal connection with the other. When understood as part of the general interest in empathic technologies [50], these two capacities of heartrate would map into the capacity of an intervention to affect a user's emotional perspective and emotional convergence with the other person. Our methodology focuses on these two dimensions and evaluates the capacity of auditory heartbeats to affect them.

2.2 Towards Empathic Auditory Interventions

Previous heartbeat sharing research has shown that the form of mediation is an important factor determining its empathic effects [66]. In essence, *how* the heartrate information is presented to a user affects their capacity for affective empathy with the other. Past research reports the results of displaying heartbeats in visual-media such as text messaging [42, 64], visualizations [37, 65, 94] or graphs [23, 64, 66], while relatively few have explored sounding heartbeats [48, 51, 52] or rhythmic vibrations [22, 102].

However, we believe that the representation of physiological signals through musical expression [60] (e.g. biomusic [96] or sonification [45]) is particularly well-suited for eliciting empathy in users. A large body of research on music has demonstrated that listeners are able to "recognize" and "feel" emotions in music [88] through a complex interaction of low-level acoustic cues [36] and higher-level cognitive processes [54]. These cues can evoke empathy through psychophysiological processes such as emotional contagion [32], entrainment [49, 53], and through pro-social changes in neurochemistry [15]. Further, these effects can be activated even outside of focused attention, as evident in the way that music shapes the perception, memory and emotion of scenes and characters in film and video games [13, 19, 61, 67, 99]. There is also a comparatively long history of expressing biosignals through music [59, 79, 86, 96], and today researchers are exploring how "biomusic systems" can elicit empathy [97] in Augmentative and Alternative Communication (AAC) systems (e.g. [11, 17]).

One of the strongest low-level acoustic cues affecting the perceived emotion of music is tempo [36], which has also been shown to affect the emotional "intensity" of auditory heartbeats [52]. Although music is not a body, or a person, expressive auditory cues such as tempo might might be used to represent internal affective states [105] and elicit empathy by triggering a physiological representation in the mind of the listener [33, 38]. This emotional response to tempo may be driving the interpersonal effects found in previous work with auditory heartbeats [48, 51, 52].

3 RESEARCH CONTEXT

Prior work on the development of empathic technologies proposed a typology of evaluation strategies that involved three components [50]: cognitive empathy, emotional convergence, and empathic responding. Cognitive empathy involves the recognition of mental and emotional states such as Theory of Mind [87]. Emotional convergence is related to affective empathy, and evokes processes relating to mimicry, synchronization and contagion. Finally, empathic responding relates to the desire of a user to alleviate distress (e.g. sympathy). Using this framework, we sought to create a study that would allow us to measure multiple facets of empathic state attributable to short-term exposure to auditory heartbeats.

There are many instruments with which to measure empathy as a long-term dispositional trait (e.g. [6, 25, 58, 85]), but there are far fewer that have been designed to measure differences in short-term, situational state-empathy. One of the prominent ways of inducing an empathic state change is through the perception of another's pain or distress [92]. For more diverse emotional states, it is common to use stimuli such as vignettes, photographs or movies depicting different socio-affective contexts [77, 84]. In the context of HCI, a variety of approaches have been introduced for the measurement of empathy in digitally-mediated representations (e.g. [24, 66]), but no study to date had explored whether such auditory signals could influence empathy in a visually-oriented emotion recognition task. We therefore sought out a dataset of diverse emotional facial expressions that could be coupled with heartbeats. Although the measurement of empathic responding (i.e. actions) is an important component of empathic technologies, for the purposes of this laboratory study on a diverse range of emotions, we chose to focus on the shifts in emotional perspective (i.e. a component of cognitive empathy [9]) and feelings of emotional convergence (i.e. a component of affective empathy).

3.1 Experiment Goal & Hypothesis

The overall goal of the experiment was to measure the effects of hearing the heartbeat of another person on empathic state. In particular, we hypothesized that hearing heartbeats would change emotional perspective (H1.1) and increase emotional convergence (H1.2), defined here as the degree to which the listener reports "feeling what the other is feeling." Further, because of the way that tempo functions as an affective cue in music, we reasoned that empathic state would also be affected by whether or not the heartbeat tempo matched the visual expression. In particular, we predicted that heartbeat mismatch would change emotional perspective (H2.1), and heartbeat match would increase emotional convergence (H2.2).

4 METHODS

We designed a randomized, counter-balanced within-subjects experiment where participants judged the emotion of a virtual person based upon the expression in their eyes and/or their auditory heartbeat. Participants then reported their ability to "feel what the other was feeling" for each trial.

4.1 Participants

We recruited 27 participants from a psychology subject pool at a large research university in the United States. Our analysis of pilot data helped us determine how many participants we would need to reach statistical significance in our final study. The sample included 21 men and 6 women and an age range of 18 to 69 years ($\bar{x}$ = 21.6, s_x = 9.5). Participants were eligible if they were between the ages of 18-69 years old, were fluent English speakers and had normal or corrected-to-normal hearing and vision. At the end of the study, participants were compensated with three credits, equivalent to three-hours of participation. Before beginning data collection, participants were provided with a consent form to review and sign. The experiment was approved by the Institutional Review Board (IRB) at that university.

4.2 Measurement & Stimuli

To efficiently represent a range of affective states and anchor participants perceptions toward the feelings of other people, we used the Reading the Mind in the Eyes Task (RMET, [6]). The RMET is a well-established and highly-used instrument for the assessment of mental and emotional perspective-taking that focuses on the identification of expressions of affect apparent in close-up photographs of eyes [30, 76]. For each eye stimulus, participants are presented with four possible affective terms, and are asked to choose the one that best represents that person's expression. The published dataset includes 36 sets of eyes representing male and female genders and a diversity of mental and affective states. The instrument has been useful in the diagnosis of autism and alexithymia and is thought to tap the emotional components of theory of mind in particular [78].

We augmented these visual stimuli with a rhythmic auditory stimulus designed to resemble the sound of heartbeats. For the purpose of experimental control, this sound was modelled in the computer music software SuperCollider [69] and played at slow (40 BPM) and fast (140 BPM) tempos. We considered other tempos in the design and piloting of our study, but decided to focus on slow and fast heartbeat tempi because we wanted to compare two groups of heartbeat tempi that were clearly differentiable and expressive of low and high-arousal states. The basis of the sound was a heartbeat sample we selected from an online search. To increase realism, we added small timing and loudness deviations, which made each heartbeat presentation unique in spite of having only one of two tempos. This randomness was modelled using a normal distribution with mean $\mu = 0$ and standard deviation $\sigma = 0.08 * 40/\beta$ where β was the desired heartbeat BPM. These parameters were tuned by ear for perceptual realism and verified by independent observers.

4.2.1 Congruent & Incongruent Stimuli. The experiment interface associated slow and fast heartbeat tempos (i.e. 40 BPM and 140 BPM) with each set of eyes in the RMET task. These eyes conveyed a diversity of expressions, and pairing them with slow or fast heartbeats created trials with heartbeat "match" and "mismatch." For example, eyes expressing "sadness" would be better associated with a slow heartbeat than a fast heartbeat, and eyes expressing "panic" would be better associated with a fast heartbeat than a slow heartbeat. To determine which eyes matched which heartbeats, we used a dataset of arousal, valence and dominance ratings associated with 14,000 English lemmas [101]. For example, the word "Angry" appears in the dataset with a valence of 2.5 ± 1.7, arousal of 6.2 ± 2.6 and dominance of 4.1 ± 2.5 as rated by 19, 20 and 44 people respectively. The dataset contained arousal ratings for all of the associated expressions in the RMET as rated by between 20 to 45 people ($\bar{x}$ = 25.25). We used these ratings to divide the images in the RMET into three groups of 12 expressions based upon their arousal rating (i.e. low, medium, high). Using these categories, we formed a group of *Congruent* audio-visual stimuli by pairing slow heartbeats with the low arousal RMET group and fast heartbeats with high arousal RMET group. We formed a group of *Incongruent* audio-visual stimuli by pairing slow heartbeats with eyes in the high arousal RMET category, and fast heartbeats with eyes in the low arousal RMET category.

4.3 Procedure

4.3.1 Pre-Test estionnaires. Before beginning the study, participants filled out questionnaires and scales to measure latent empathetic traits, personality, musicianship and basic demographics. These questionnaires included the Interpersonal Reactivity Index [25], Toronto Empathy Questionnaire [95], Emotional Contagion Scale [31], Short Big-5 Inventory [39], and the Musical Training, Perceptual Abilities and Active Engagement portions of the Goldsmith Musical Sophistication Index [75]. The pre-test questionnaires also included the RMET in its standard form [6] where the order of the eyes was not randomized, there were no auditory heartbeats, and participants answered each question at their own pace. This baseline RMET was applied to our analysis of change in emotional perspective, allowing us to determine changes attributable to differences due to our experimental conditions and those due to our experimental design (Sec. 5.2).

4.3.2 Stimulus Presentation & A ect A ribution. Each trial began by presenting a selection from the RMET to the participant. The interface displayed a set of eyes and four affective labels. The participant was invited to select the label that best answered the question, "What is this person feeling?" Each stimulus presentation lasted 20 seconds. We used a fixed trial duration because we wanted answers to the emotional convergence question (Sec. 4.3.3) to be based upon equal amounts of exposure to the stimulus. We also viewed this as a means to increase the quality of responses because the overall trial length could not be reduced with hastily chosen answers. We believed that 20s would be ample time for participants based upon our piloting, and as a fail-safe, we programmed the experimental software to wait for participant's response before continuing. In our experiment, participants' average response time for the first question was 8.3 +/- 4.6 seconds. We furthermore instructed participants that if they made their selection early, they should continue imagining what the virtual person was feeling until the stimulus presentation period ended. A "Next" button appeared once the stimulus presentation period had ended and they had made a selection, allowing them to continue when ready.

In the experiment interface, the four affective labels appeared on buttons distributed on the corners of the image and changed color upon participant selection. The original RMET provided a dictionary with definitions of each of the affective labels. For ease of access, we embedded these definitions as "tooltips" that would appear when hovering over the associated button. To reduce learning effects, the positions of the affect labels were randomized for each trial. Figure 1a shows an example of the presentation of Question 1 for a practice trial.

4.3.3 Reporting Emotional Convergence. After answering the stimulus presentation portion of the trial, participants moved to the second part. This question asked: "How well did you feel what they were feeling?" and referred to their affective experience during the stimulus presentation. Participants responded on a seven-point likert scale from "Not well at all" to "Extremely well." This portion of the trial lasted a minimum of 10 seconds, and if the participant finished early, they were invited to rest before the next trial. A "Next" button would appear allowing them to continue when ready. Figure 1b shows the presentation of the affective empathy question as presented in the experiment interface.

4.3.4 Conditions & Randomization. The final experiment contained 144 trials: one complete RMET for each of four conditions: *Visual-Only* (silence), *Audio-Only* (heartbeat-only), *Audio-Visual Fast* and *Audio-Visual Slow*. These four conditions appeared 36 times in the experiment (one for each of the 36 trials in the RMET), but were randomly distributed within the study. The *Audio-Only* stimuli contained an equal number of slow and fast trials, but these were randomly distributed within the RMET for each participant. To prevent close repetition of one of the 36 trials within the RMET, these were independently randomized so that the RMET would appear in its entirety before repeating. A diagram visualizing our approach to trial randomization is provided in Figure 2. By using a full factorial design with 36 trials per condition, we were able to obtain 144 samples for each measure per participant, increasing statistical power and requiring fewer participants.

5 RESULTS

5.1 Dependent Variables & Statistical Analysis

Each trial of the experiment included two questions designed to measure cognitive and affective components of transient empathic state. These questions were:

(1) "What is this person feeling?"
(2) "How well could you feel what they were feeling?"

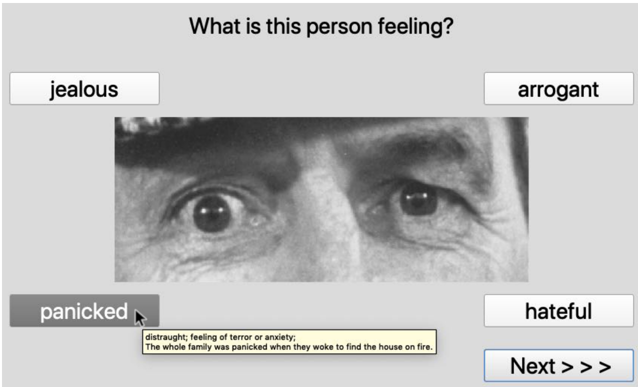
5.1.1 Emotional Perspective Measure. From their responses to the first question, we created a binary dependent measure reflecting whether there was a "Change" (1) or "No Change" (0) from the participant's pre-trial baseline RMET. We called this variable *RMETChange*. Because the change was relative to a visual-only presentation, responses from the *Audio-Only* conditions were excluded. Further, because of a technical error, 7 participants did not receive the baseline RMET, and they were excluded from the analysis.

Because *RMETChange* was binary, we applied logistic regression and the Wald χ^2 Test to determine if our explanatory variables were significant. We then used the odds-ratio (Exp(B)) to determine the likelihood that a participant would change their selection based on that variable.

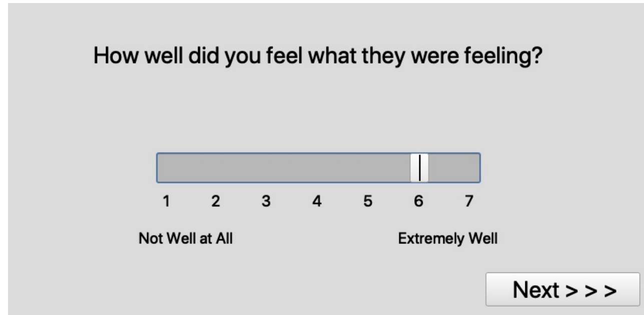
5.1.2 Emotional Convergence Measure. The second question measured the degree to which participants felt the feelings of the observed person (i.e. "emotional convergence"). Participants provided their responses on a seven-point Likert scale. We reasoned that responses would vary systematically between participants due to their emotional responsiveness and interpretation of the question. Therefore, in order compare the responses across all participants, we first standardized each participant's responses independently using the z-score:

$$z(x) = \frac{x - \bar{x}}{s_x} \quad (1)$$

Where $\bar{x}$ is the mean response for the participant across all 144 trials, s_x is the standard deviation of the participant's responses across the 144 trials, x is the participant's response for a given trial,



(a) The emotional perspective question.



(b) The emotional convergence question.

Figure 1: Our study measured cognitive and affective components of empathic responses to auditory heartbeats.

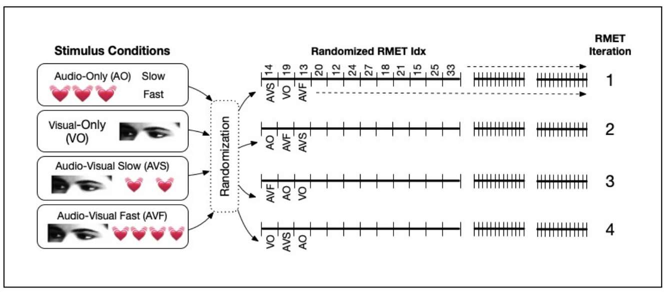


Figure 2: A diagram of the trial ordering in the experiment. Four randomized iterations of the 36 RMET trials were presented in sequence and paired with one of the four conditions: *Audio-Only, Visual-Only, Audio-Visual Slow* and *Audio-Visual Fast.* These 144 trials were grouped into 12 blocks of 12 trials.

and $z(x)$ is the z-score for that trial. The resulting transformation guaranteed that each participant's mean response was centered around zero, and had a standard deviation of one. We called this derived measure *FeelingStrengthZScore*.

To test if *FeelingStrengthZScore* was statistically different in our conditions, we applied a General Linear Mixed Model (GLMM) [18]. This is a modern univariate approach that generalizes a variety of models into one single model with both random and fixed factors [89]. In our analyses, we treat participants as a random factor, and explicitly model the factors of interest.

5.2 Effect of Heartbeats

We hypothesized that hearing the heartbeat of another person would change emotional perspective (H1.1) and increase emotional convergence (H1.2). As presented in Section 5.1.1, to determine if there was a statistically significant change in emotional perspective, we applied a simple logistic regression to predict *RMETChange* in the *Visual-Only* (N = 720) or *Audio-Visual* (N = 1440) conditions. A significant regression was found with χ^2 = 14.07, df = 1, Exp(B) = 1.207, p < .001, meaning that the presence of heartbeats was a significant predictor of *RMETChange*. Further, participants were 21% more likely to select a different emotion label when they heard the imagined person's heartbeat. This rejects the null hypothesis for H1.1., i.e., the auditory heartbeat of another person changed participants' perspective on what that person was feeling (emotional perspective). Figure 3a displays the proportion of changes in the RMET selection from baseline in the *Visual-Only* and *Audio-Visual* Conditions.

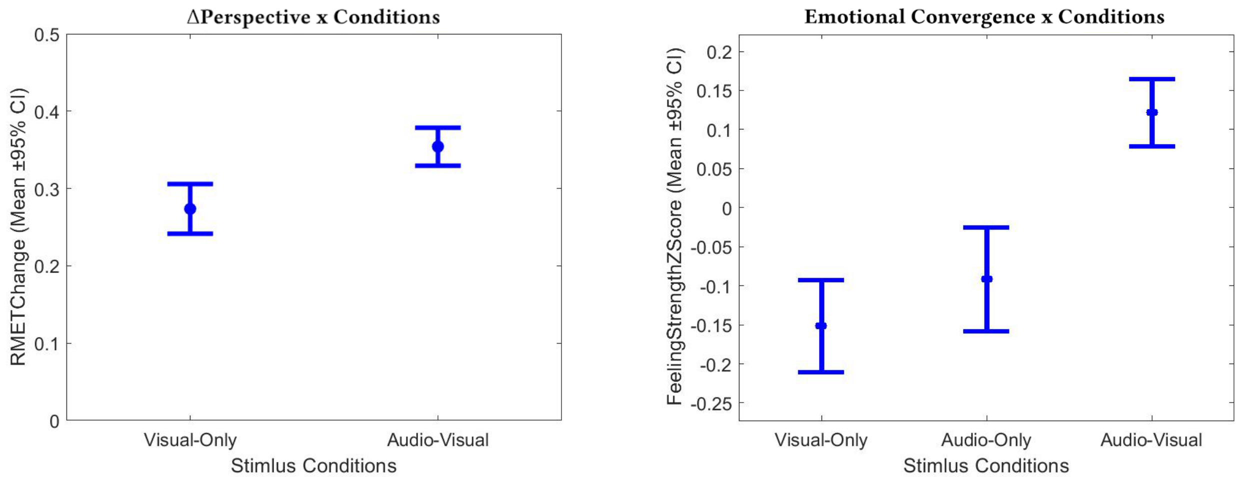
As presented in Section 5.1.2, to determine if there was a statistically significant increase in emotional convergence, we used a GLMM to compare the mean *FeelingStrengthZScore* between the *Visual-Only* (M = -.152, SD = .022), *Audio-Only* (M = -.092, SD = .032) and *Audio-Visual* (M = .122, SD = .022) conditions. The effect was of heartbeats was significant [F(2, 52) = 5.46, p =.007]. This rejects the null hypothesis for H1.2., i.e., hearing heartbeats increased emotional convergence in the listener, as revealed in their answers to the question, "How well did you feel what they were feeling?"

We performed a multiple comparison test on *FeelingStrengthZScore* using a Bonferroni correction and found that the ratings in the *Audio-Visual* condition were significantly higher than the *Visual-Only* condition (p < .001; d = 9.98) and the *Audio-Only* condition (p < .001; d = 7.79). Furthermore, there was no statistically significant difference between the *Visual-Only* and *Audio-Only* conditions. This means that the increase of empathy was not due to the audio alone, but rather due to the association of the auditory heartbeat with the eyes of the imagined person. Figure 3b displays the means and 95% confidence intervals for these conditions graphically.

5.3 Effect of Heartbeat Match

As discussed in Section 4.2.1, our experiment design allowed us to test if audio-visual congruency ("heartbeat match") would effect emotional perspective. If so, this would mean that listeners' perspectives on the what the other person was experiencing depended on the affective relationship of the heartbeat tempo and visual stimulus.

To determine if there was a statistically significant change in emotional perspective, we applied a simple logistic regression to predict *RMETChange* based upon whether the audio-visual stimuli



(a) Heartbeats changed listener's perspective.

(b) Heartbeats increased ratings of emotional convergence.

Figure 3: Comparisons of the effects of heartbeats on our two measures of empathic state.

were *Incongruent* (N = 480) or *Congruent* (N = 480). A significant regression was found with χ^2 = 10.61, df = 1, Exp(B) = 1.564, p = .001, meaning that heartbeat match was a significant predictor of *RMETChange*. Participants were 56% more likely to change their emotion label when the tempo of the heartbeat did not match the emotion in the eyes. This rejects the null hypothesis for H2.1., i.e., heartbeat mismatch created more changes in emotional perspective. Figure 4a displays the proportion of changes in the RMET selection from baseline in *Congruent* and *Incongruent* audio-visual stimuli.

To determine if there was a statistically significant increase in emotional convergence due to the heartbeat match, we used a GLMM to compare the mean *FeelingStrengthZScore* between the *Congruent* (M = .229, SD = .038) and *Incongruent* (M = .043, SD = .038) audio-visual stimuli. The effect of congruency was significant [F(1,26) = 10.49, p = .003; d = 4.89]. This rejects the null hypothesis for H2.2., i.e., heartbeat match increased emotional convergence in the listener, as revealed in their answers to the question, "How well did you feel what they were feeling?" Figure 4b displays the means and 95% confidence intervals for these conditions graphically.

6 DISCUSSION

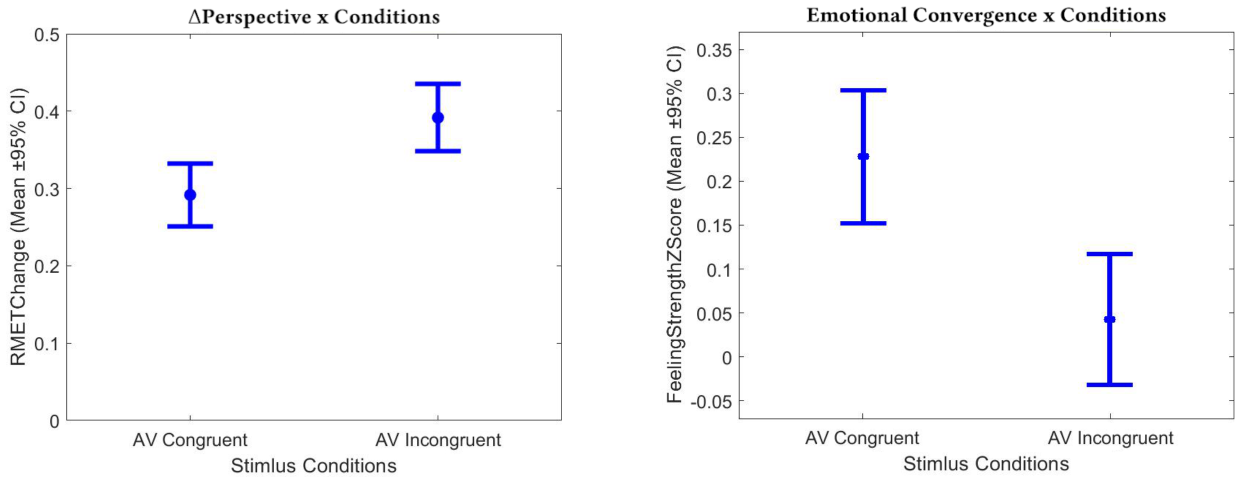
Our results have shown that hearing the heartbeat of another person affected multiple components of empathic state. In particular, hearing heartbeats caused a change in emotional perspective (H1.1), and an increase in emotional convergence (H1.2). Furthermore, these changes depended upon whether the heartbeat tempo "matched" the expression in the eyes (H2.1 & H2.2).

6.1 Auditory Heartbeats as an Empathic Intervention

Recent work has demonstrated that *how* an expressive biosignal is displayed is an important factor influencing a user's empathic response [66]. However, while prior work had shown that biosignals can affect emotional perception and connection to others, this research had primarily used visual methods such as graphs [23, 24, 66] visualizations [37, 65, 94] and text [42, 64] for representing the biosignal. By contrast, there is a relative lack of research on the empathic effects of auditory biosignal display [48, 51]. To this line of research, we contribute a controlled laboratory study that measured the effects of auditory display of heartrate on multiple components of empathic state. Using this method, we were able to demonstrate that short-term exposure to auditory heartbeats could change a listener's perspective on the emotional state of another person, and increase their feelings of emotional convergence. Together, these findings demonstrate that auditory heartbeats are well-suited as an empathic intervention.

By using the RMET, we have also demonstrated the ability of auditory heartbeats to change emotional perspective during a facial emotion recognition task. The strength of this auditory cue of arousal is striking given that facial expressions—particularly the eyes—are a strong determinant of perceived affect [6, 68]. The capacity to change emotional perspective was especially evident in *Incongruent* audio-visual stimuli where the tempo of the heartbeat did not "match" the expression in the eyes. In these cases, participants may have used the heartbeat tempo as information about the affective state of the person that was not otherwise apparent, and integrated the visual and auditory signals before making their response. In either case, our results demonstrate that this auditory cue changed perceived emotion in a visual scene, similar to the well-known emotional effects of music on film [19, 67]. However, by contrast to the complex patterns of auditory cues commonly found in music [36], we demonstrate this effect using a simple sonification of heartrate attributed to the affective state of another person.

Our experiment design allowed us to simultaneously measure another component of empathic state—emotional convergence, here defined as the ability to "feel what the other was feeling." We found that auditory heartbeats increased ratings of emotional convergence in the *Audio-Visual* condition and that there was no statistically significant difference in emotional convergence ratings between the *Visual-Only* and *Audio-Only* conditions. Combining



(a) Heartbeat mismatch changed listener's perspective.

(b) Heartbeat match increased ratings of emotional convergence.

Figure 4: Comparisons of the effects of heartbeat match on our two measures of empathic state.

these findings, we argue that auditory heartbeats can increase emotional convergence during facial emotion recognition. Furthermore, auditory heatbeats can produce similar levels of emotional convergence as seeing emotionally expressive eyes in the absence of an accompanying visual expression. This result supports prior work demonstrating that auditory heartbeats can produce similar interpersonal affective responses as more common social signals such as gaze and interpersonal distance [51], but extends it by measuring changes in multiple components of empathic state, using a range of visual expressions, and by contrasting congruent and incongruent heartbeat tempi.

By measuring multiple components of empathic state, we were able to quantify interactions between the two measures. In particular, we found that heartbeat matches produced higher-levels of emotional convergence than heartbeat mismatches, but fewer changes in the perceived emotion. Further, heartbeat mismatches created more changes in the observed emotion, but also lower levels of emotional convergence. This result highlights the need for researchers to measure the effects of empathic interventions as multidimensional constructs [26, 50], and to study the interactions between the perception of internal physiological signals and external socio-affective expressions.

6.2 Promising Application Groups & Use Contexts

Having shown that auditory heartbeats can function as an empathic intervention, new questions arise as to particular users, use-contexts and technological interventions that might benefit from their application. Fundamentally, as an auditory display, we argue that auditory heartbeats will be useful as a complement or alternative to visual displays of affect. For example, Hassib et al.'s *HeartChat* [42] shares heartrate through a text-messaging interface and Liu et al.'s *Animo* [65] represents heartrate through playful visualizations. In either case, a short auditory heartbeat representing the user's heartrate could be added to the existing system, complementing their empathic qualities without altering the visual design. Another promising avenue for application is as an affective AAC technology, such as those developed for biomusic systems [10, 11, 17, 40, 97]. When applied in such a system, people with difficulties expressing affect outwardly could use auditory heartbeats to help others to interpret their internal affective state and increase feelings of emotional connection.

A particularly interesting finding of this study was that hearing the heartbeat of another person produced equal levels of emotional convergence as seeing their eyes in the absence of heartbeats. This finding lends itself to the application of auditory heartbeats as an alternative to visual display. People who are blind due to situational or dispositional factors might be able to use auditory heartbeats to access and connect to the affective state of someone they cannot see. For example, auditory heartbeats could be applied to display arousal detected in facial expressions (e.g. [4, 91]), helping users access important non-verbal cues in realtime communication. When added to complement the empathic qualities of biosignal visualizations (e.g. [3]), auditory heartbeats may also help to make these systems more inclusive [71]. Because they do not require a screen or a particular field of view, auditory heartbeats may be applied in similar contexts as wearable technologies that "broadcast" biosignals or affective states to others in the immediate vicinity [46, 47, 100] or mediate realtime dyadic emotional communication [65, 90]. Importantly, as a display strategy, auditory heartbeats can be applied to communicate arousal originating from any affective biosensing technology.

One population in particular that may benefit from auditory heartbeats as an empathic intervention are people living with Autism Spectrum Disorder (ASD). People with ASD experience difficulties reading others' thoughts and emotions, making judgements and decisions based social information, and interpreting affective cues such as facial expressions, gestures and tone of voice [8, 35, 73]. One manifestation of the disorder is an impaired theory of mind [5], which can restult in reduced empathy in ASD [9]. In spite of these difficulties, multiple studies have found that emotional reactions of people with ASD to music are unaffected and no different than people without the disorder [1, 43, 44]. These results suggest that music provides cognitive and affective cues that people with autism can understand [8], which may be applied to repair the link between autonomic and cognitive components of emotion and become a "powerful tool" for the clinical treatment of alexithymia [2]. Because of the strong affective associations of musical tempo [36], people with ASD might be able to associate the tempo of the heartbeat with the arousal of the other person and use it to understand and connect to their feelings.

6.3 Evaluating Empathic Interventions

To our knowledge, this is the first controlled laboratory study to evaluate the effects of an empathic intervention in a facial emotion recognition task. Through our methodology, we demonstrated that our auditory intervention resulted in changes in two components of empathic state, which provided a more comprehensive understanding on how these measures were related to each other and our different experimental conditions. Previous work has argued that empathy should become the core research framework for studying new affective communication technologies, and use methods and evaluation strategies from the psychology of empathy [50]. We demonstrate how well-established methods for evaluation originating in social psychology (i.e. RMET [6]) can be borrowed or applied to evaluate the effects of these new empathic interventions.

This work has shown how hearing an expressive biosignal can affect multiple components of empathic state, and has demonstrated it using a simple mapping strategy (i.e. heartrate → tempo). However, there are many other signals that could be used as the basis for an empathic technology and many more auditory mapping strategies that could elicit empathic effects. Others have been interested in the effects of sharing signals like skin conductance [17, 24, 46] or breath [34, 72] for example, and biomusic AAC technologies apply aesthetically nuanced combinations of auditory mappings (e.g. breath → musical phrase [11], skin conductance → melodic pitch [17]). As new empathic auditory interventions are designed, researchers will need some metric with which to compare the effects of different designs. To this line of work, we provide a baseline for evaluating future empathic technologies and systems. Researchers that apply this method will be able to compare the empathic effects of their system relative to a more simple approach. Furthermore, standardizing the evaluation strategy will allow researchers in the field to more easily compare the effects of different empathic auditory interventions.

7 LIMITATIONS & FUTURE WORK

We decided to focus on slow and fast heartbeat tempi because we wanted to compare two groups of heartbeat tempi that were clearly differentiable and expressive of low and high-arousal states. This contrast was essential for distinguishing congruent and incongruent stimuli groups. Having established effects of auditory heartbeats and their tempo, future work could benefit from a "neutral" heartbeat control condition, and even finer tempo gradations, which could help explore the effects of heartbeats and heartbeat tempo in greater detail.

By using the RMET, we have studied the effects of auditory heartbeats on a widely-used measure of mental and emotional perspective taking that is quick to administer and includes a diversity of emotional expressions [6, 30, 76]. However, several features of this measure limit its ecological validity and our ability to generalize our results to wider use-cases. First, the sample contains entirely static images of eyes, whereas in real-life, emotions are often expressed through complex multimodal expressions (e.g. gross motor gestures, tone of voice and full facial expressions) [74]. Furthermore, the sample itself is composed entirely of Caucasian males and females, "correct" answers are determined from consensus scoring, and verbal responses require some nuanced vocabulary (e.g. *despondent*, *imploring*). For these reasons, performance on the test is known to vary with a variety of socio-cultural factors including education, race and ethnicity, gender and social class [29, 30, 55]. We partially accommodate for these biases by measuring *change* in emotional perspective as opposed to whether the chosen emotion-label was correct or incorrect. In order to generalize these findings, future work should use an updated baseline measure that contains a wider field of view, dynamic facial expressions, a more diverse sample of people, and perhaps additional narrative context, like has been provided through research with vignettes [66, 70]).

Our study used the RMET as a pre-trial baseline, and again in different A/V conditions through the study, which may have resulted in learning effects. However, by using a randomized and counter-balanced design, any learning effects would have been distributed evenly in all conditions. Further, because our *Visual-Only* was equivalent to the RMET minues the changes introduced by the experimental design, any additional effects could be attributed to the treatment. Future studies could further limit learning effects by using fewer repetitions of the RMET, and more participants to increase between-subjects samples.

8 CONCLUSION & FUTURE WORK

In this paper, we presented a baseline empathic auditory intervention using auditory heartbeats. We demonstrated that heartbeats can influence cognitive and affective components of empathy in the context of a visually-oriented emotion recognition task. The performance of auditory heartbeats relative to the visual-only condition indicates that heard heartbeats changed emotional perspective and increased emotional convergence. As a controlled, lab-based study, our goal was to further knowledge about these auditory interventions that could be generalized and applied to other systems. Based upon our results, we believe that auditory heartbeats are well-suited as an empathic auditory intervention in the adult population, and may be particularly useful to groups and contexts as a non-visual display that uses a salient cue of affective arousal (i.e. tempo). Applying heartbeats in interactive social systems provides one way that HCI can use affective auditory cues to create more empathic technologies.

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