Habits of the Heart(rate): Interpretation and Behavior from Biosignals in Uncertain Social Interactions

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ABSTRACT

This paper investigates how individuals interpret the social meaning of a biosignal (heartrate) in the context of uncertain social interactions with another person. We employ a mixed-methods study involving both a vignette experiment and a laboratory-based experiment in which participants viewed heartrate information about someone else in an uncertain situation. In both experiments, we find that individuals generally make negative mood attributions towards partners with elevated heartrates. However, we find that contextual meaning of an elevated heartrate changes depending on the social situation. In the lab-based trust experiment, individuals cooperate less often with those who have elevated heartrates. In the vignette study, however, we find qualitative evidence that individuals interpret elevated heartrate in a way that is more favorable to the partner. We discuss the implications of our findings in the context of a growing interest in computer-supported collaborative and interactional technologies, and the ubiquity of wearable, physiological sensors.

Author Keywords

Computer-mediated communication; biosignals; heartrate; trust; cooperation

ACM Classification Keywords

H.5.3 Information Interfaces and Presentation: Group and Organization Interfaces

INTRODUCTION

What could your heartrate possibly tell another person about you? Past work has generally cited enhanced intimacy as a possible outcome of heartrate sharing [2, 25, 24, 29, 15, 16]. But, could the transmission of low-level signals like heartrate result in negative consequences as well? If so, under what kinds of interaction situations might these interpretations differ?

As biosensors become smaller and cheaper, more consumer devices are presenting users and application designers with opportunities to share their physiological data with others. For example, high-profile technologies such as the Apple Watch explicitly advertise the ability to share heartrate between friends [23]. However, we do not know how people will interpret this signal in social contexts. In fact, it is not well understood how people build interpretations around biosignals at all, or how these interpretations vary in different social situations.

In many cases, the presumed authority and objectivity of biosignals motivates their collection. At least one insurance company offers discounts to users who use wearable fitness trackers [5]. Behavioral correlates might motivate collection as well: recent research suggests a correlation between low resting heartrate and involvement in violent crime [1]. While statistical findings on biosignals may spur broader collection, it is not clear that these empirical interpretations will always match their social, interpretive meanings *in situ*. How human actors encounter and interpret low or elevated heartrate may differ from algorithmic and scientific correlations. As this type of raw biometric data is made socially shareable, as in some recent interfaces, we must examine how algorithmic interpretations and social interpretations of these data might diverge.

In this paper, we describe the quantitative and qualitative results of a mixed-methods study involving a vignette experiment and a controlled laboratory experiment in which individuals viewed heartrate information about someone else. In our vignette experiment, subjects were asked to make assessments about a person based on an imagined scenario that included shared heartrate information. In our laboratory experiment, subjects saw the heartrate of their partner while playing a repeated trust-building game. In our lab-based experiment, we found that individuals tend to be less cooperative with those who have elevated heartrates relative to those who have normal heartrates, while entrusting behavior did not differ based on the partners' heartrate. In both of our experimental studies, empirical results indicate that individuals generally make more negative mood attributions about partners with elevated heartrates compared to normal heartrates. However, differences in the situations described in our vignette study versus the lab-based trust game indicate that the social *meaning* of these assessments can vary widely (either positively or negatively) depending on the context of interaction.

The results of this study enhance and complicate the role of biosignal information sharing and social interpretation in HCI, deepening the conversation around physiological information into the complex, contextual territory occupied by other signals in computer-mediated communication (CMC) [2, 3, 7, 20]. Trust-building and cooperation are of particular importance in this regard, because many physiological signal sharing devices purport to enhance such behaviors [22, 13, 26], and because trust and cooperation are central to interpersonal computer-mediated interactions [3, 4, 7, 19, 27]. Through our investigation of heartrate sharing, we shed light on how social interpretations of biometric data are associated with attributions about another persons' mood and potential behavior, as well as trusting and cooperative behaviors towards others.

BUILDING SOCIAL INTERPRETATIONS AROUND PHYSIOLOGICAL SENSORS

A relatively large body of work has looked at how the transmission of sensor data might play a role in computer-mediated communication, especially the transmission of physiological data. One class of applications has attempted to explicitly encourage or discourage certain behavioral outcomes, making some biosignals apparent such that the transmission of the data acts as a social cue [6, 22, 13]. Another class of prototypes explores how signals might affect feelings of intimacy [25, 24, 29, 15, 116], particularly between intimate partners [2], and several applications focus on the transmission of heartrate as a means to achieve this effect [20, 2, 15, 16].

Despite a number of applications in which biosignals are transmitted socially between users, there remains little work on how people interpret biosignals they see from others [20]. Past studies on heartrate sharing indicate that people do read social emotional cues in the heartrates of other people [20, 15]. However, it is not well-understood what social *meanings* these signals take on in different social contexts, and, in contrast to the findings of previous studies, it is not clear that the social consequences of transmitting physiological data will always be positive (e.g., increased intimacy).

Interpretations of one's own physiological signals are slightly better understood from empirical research. With particular regard to heartrate information, individuals' interpretations of their own heartrate have received the most attention [17, 21] (see [26] for a review), and studies have generally revealed that elevated heartrate can yield negative emotional interpretations for oneself. In summary, this line of work indicates that when individuals believe that their heartrate is elevated, they often believe their mood and emotions to be more negative.

If lay interpretations of one's own heartrate can yield negative self-interpretations, sharing heartrate information could also yield negative effects on cooperation, trust, and general assessments about other people, especially during uncertain interactions where something is at stake (such as time, money, or other valued resources). To investigate, we use a mixed-methods approach combining quantitative and qualitative analyses of two key studies: (1) a survey-based vignette experiment, and (2) a laboratory-based interpersonal trust game.

INTERPRETING BIOSIGNALS UNDER UNCERTAINTY

We seek to explore whether information about another person's heartrate, in the absence of other cues, could negatively affect attributions, cooperation, and trust towards another person during risky, uncertain interactions. We focus exclusively on heartrate due to its established link to interpretations of emotion, as well as the ubiquity of heartrate sensors in consumer devices such as the Apple Watch and the BASIS smartwatch.

Our investigation begins with two key predictions about negative assessments of one's partner in an uncertain social situation. Based on aforementioned studies of individual's negative emotional interpretation of their own heartrate, we believe that this negative valence will be mirrored in people's interpretations of the heartrates of others in uncertain situations.

Hypothesis 1: When individuals believe that their partner has an elevated heartrate in an uncertain social interaction, they will make negative attributions about the partner, including anxiety level (1a), calmness (1b), and whether the partner is emotional (1c), or easily upset (1d), compared to those who believe that their partner has a normal heartrate.

If elevated heartrate acts as a negative cue about another person's state of mind, we would also predict that seeing an elevated heartrate should increase uncertainty about the partners' behavior in the interaction. Thus, when partners see that their partner has an elevated heartrate (compared to normal), they will have a more negative assessment about the partners' potential behavior (e.g, assessments of the trustworthiness, reliability, and dependability of the partner).

Hypothesis 2: When individuals believe that their partner has an elevated heartrate in an uncertain social interaction, they will make negative assessments about how much certainty they can place in the partner's behavior, including trustworthiness (2a), reliability (2b), and dependability (2c), compared to those who believe that their partner has a normal heartrate.

A SURVEY-BASED VIGNETTE EXPERIMENT (STUDY 1)

To test our first two hypotheses, we conducted a survey-based vignette experiment. Vignette studies involve short descriptions of a scenario, designed to elucidate opinions, attitudes, and beliefs about that particular situation [10].

In this particular vignette study, we described a scenario in which a person is waiting at a movie theater for an acquaintance so that they can see a film together. However, the acquaintance sends a message via smartphone indicating that he or she is running late due to slow traffic, and the movie starts in just five minutes. This particular scenario creates one type of uncertain social situation: the person who is waiting does not know if the acquaintance will make it on time or not, or whether the acquaintance is being honest about their tardiness.

Since we are interested in the social interpretation of biosignals in uncertain situations, we manipulate a small piece of information about the heartrate of the acquaintance. Specifically, we tell the participant that the heartrate of the acquaintance has been shared by the acquaintances' smartphone and it is either elevated or normal, depending on the vignette condition.

Methods in Vignette Study

Our sample was undergraduate students recruited from the population of a large, West Coast public university. Potential participants were asked to participate in a short online survey, and they did not know the nature of the questions or the topic of the study in advance. All participants were paid a $5 Amazon gift card. Eighty participants (80) completed the experiment, 52 women and 28 men. The mean age of participants was 24.

Participants in the survey saw a short vignette asking them to imagine themselves in a social scenario. The survey included free response questions about subjects' reactions to and interpretations of the situation described in the vignette, as well as 7-point Likert scale questions (Strongly Agree to Strongly Disagree) in which subjects evaluated the other person's disposition ("This person is emotional", "This person is anxious", "This person is easily upset", and "This person is calm"). In addition, we asked participants to indicate whether the other person was "trustworthy," "reliable," and "dependable" using the same 7-point agreement scale.

Participants were randomly assigned into one of two conditions: 'elevated' heartrate (EH) information or 'normal' heartrate (NH) information. We manipulated these two vignette conditions by making a key wording change as indicated in this text:

You planned to meet your acquaintance for a movie at seven. It's 7:15, and you're standing alone in front of the theater. Your phone buzzes, and you see a message from this person that says, "I'm running late, traffic was really slow." Through your smartphone, you are able to see this person's heartrate, which the app designates as [condition 1= *normal* / condition 2 = *elevated*]. *It is currently 75 degrees and sunny. Your movie starts at 7:20.*

VIGNETTE RESULTS

Our first hypothesis predicts that individuals will make negative attributions about the acquaintance in this uncertain situation when they believe that the acquaintance has an elevated heartrate (compared to normal heartrate). We found an overall strong, statistically significant effect and medium practical association between attributions and vignette condition ($F(4, 49) = 16.3$, $p < .0001$; Wilk's lambda = .43, partial eta squared =.57). Turning to the individual outcomes, we find that perceptions of the acquaintances' anxiety is significantly higher in the EH condition ($M = 4.81$, $SD = .98$) compared to the NH condition ($M = 2.89$, $SD = 1.39$), $F(1, 52) = 33$, $p < .001$; partial eta squared = .39. Furthermore, participants rated the acquaintance as significantly more calm in the NH condition ($M = 5.43$, $SD = 1.03$) compared to the EH condition ($M = 3.23$, $SD = 1.03$), $F(1, 52) = 61$, $p < .001$; partial eta squared =.54. Perceptions about whether the acquaintance was easily upset were also significantly higher for the EH condition ($M = 4$, $SD = 1.2$) compared to the NH condition ($M = 2.93$, $SD = 1.09$), $F(1, 52) = 11.8$, $p < .001$; partial eta squared = .19.

We found no significant difference in assessments of how 'emotional' the acquaintance was in the EH condition ($M = 3.65$, $SD = .97$) versus the NH condition ($M = 3.39$, $SD = 1.32$). In sum, we find strong statistical and practical differences in perceptions of anxiety, calmness, and whether the acquaintance is easily upset, but no statistical or practical differences in how emotional the acquaintance appears to be in the two vignette conditions. With clear statistical and practical significance for 3 of the 4 attributions (1a, 1b, and 1d), Hypothesis 1 is supported.

Our second hypothesis predicts that individuals will make negative assessments about how certain they can be about the acquaintances' behavior when they believe the acquaintance has an elevated versus a normal heartrate. However, we find no statistically or practically significant effect for these outcomes by condition ($F(3, 50) = .95$, $p = .42$); Wilk's lambda = .95, partial eta squared =.05). The means for all three outcomes, reliability ($M = 3.8$, $SD = 1.3$), dependability ($M = 3.7$, $SD = 1.14$), and trustworthiness ($M = 4$, $SD = .97$), were essentially equivalent between conditions. Hypothesis 2 is not supported.

Qualitative Results

Directly after the vignette, participants were asked four, free-response questions about their reactions to the situation described in the vignette: 1) How do you react to this message, 2) What makes you react this way, 3) What is the ideal outcome of this situation, and 4) What is the worst possible outcome of this situation? The open-field responses were coded into two broad, non-overlapping categories: those that mentioned a negative emotional reaction to the scenario, and those that included a mention of what the other person in the situation might be thinking or feeling. Responses in the latter category were further sub-divided by experimental condition for analysis.

Interpretations of a Non-elevated Heartrate

Of those respondents who mentioned some interpretation of the other person's thoughts or motives in the normal heartrate condition, a clear majority voiced doubts about the other person's honesty, taking their *lack* of an elevated heartrate as a possible cue.

"I feel frustrated because it seems like the person isn't concerned about making me wait."

"It seems like they are too nonchalant about it"

"At first I believe that maybe my acquaintance is running late; however when I discover that their heart rate is normal I wonder why it isn't higher…"

Conversely, two participants read the normal heartrate in exactly the opposite way: As a sign that the other person was trustworthy in their proclamation that they were running late and had hit some traffic.

"If his heartrate is normal, then he is probably not lying. I would still be slightly annoyed at this."

"if this is a movie I was looking forward to- i will be upset but not pissed. its OK.her heartbeat was normal, so no lies"

Of all the responses, we noted one participant who explained that there was not necessarily a connection between the heartrate and the scenario.

"There may be reasons why his/her heartrate is normal and why he/she may be late in the first place, so I'm not concerned about that."

Interpretations of an Elevated Heartrate

In the high heartrate conditions, nearly *all* responses that included interpretations about the other person indicated interpretations of anxiety in the other person. In some case, participants found the heartrate reaction alarming:

"My initial reaction would probably be to ask them if everything['] s okay."

However, while the elevated heartrate information appeared to indicate anxiety, the majority of respondents expressed that the elevated heartrate was a token of authenticity: either meaning that the other person cared about being late, or at least that their situational reality was severe enough such that it provoked (i.e. is causally responsible for) the observed, elevated heartrate. For example:

"Elevated heart rate tells me that the acquaintance at least cares that he/she is late and there's no point in getting mad."

All of the respondents who mentioned the elevated heartrate attributed it to direct phenomena mentioned in the vignette, and not, for instance, to the person's overall demeanor, to sensor failure, or any other characteristic. In large part, this is to be expected since the vignette was designed to focus on only the key information and to limit extraneous information or comparisons.

Remarkably, none of the responses in the elevated heartrate condition included any mention of skepticism about the other person's honesty in their report, whereas these sorts of reports were prevalent in the normal heartrate condition. It is also interesting to note that only one subject in the entire experiment commented on the potential for invasiveness or over-disclosure in heartrate sharing.

"I feel like I'm violating my acquaintance's private information by knowing their heart beat, which is why I feel confused."

The vignette scenario was contrived from believable, but currently non-existent smartphone technology. Either due to participants' suspension of their disbelief or due to their actual attitudes about the heartrate sharing, privacy implications of the mentioned technology did not surface in the free responses aside from the prior excerpt.

A BEHAVIORAL EXPERIMENT (STUDY 2)

In order to evaluate actual (versus imaginary) behaviors in an uncertain situation with biosignals, we conducted a repeated trust experiment with shared heartrate information. Trust games present subjects with financial incentives to pay attention to their partner's decisions over time, and provide means for operationalizing trust and cooperation in the presence of uncertainty [4].

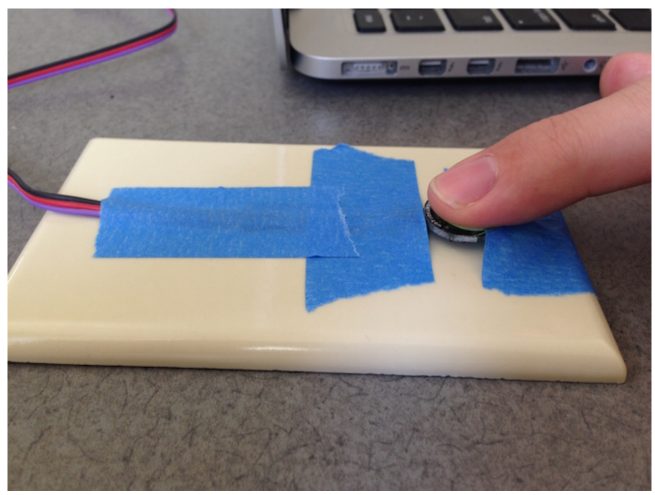

Figure 1. The heartrate monitor. Subjects were told to place their finger on the monitor to take a reading while viewing their partner's decisions during the previous turn.

The basic design of the trust game involves anonymous pairs of fixed partners making repeated decisions to entrust valued resources to the partner, and to return (cooperate) or keep (defect) the points entrusted by the other partner. Importantly, individuals can make the highest amount of money when they entrust many points to a partner and the partner returns these points. This situation creates a different kind of uncertain social interaction than the vignette study: the participants in the repeated trust game are trying to earn real money by repeatedly taking risks (entrusting points) to a partner. Since the partners are making the same decisions to entrust and keep/return points from the other partner, these are mutually-dependent social interactions.

Based on the results of the vignette study, we already have strong empirical evidence that elevated heartrate can act as a negative cue about another person's state of mind. We test this hypothesis (Hypothesis 1) again using the different scenario in the lab experiment. In addition, the controlled setting of a lab experiment now allows us to examine *actual* behavioral outcomes instead of assessments of *potential* behavior (e.g., Hypothesis 2). In addition to re-evaluating Hypothesis 1, we now examine two additional behavioral hypotheses instead of Hypothesis 2. These two new hypotheses focus on an individual's own behavior as they repeatedly interact with a partner who is sharing their heartrate information over time.

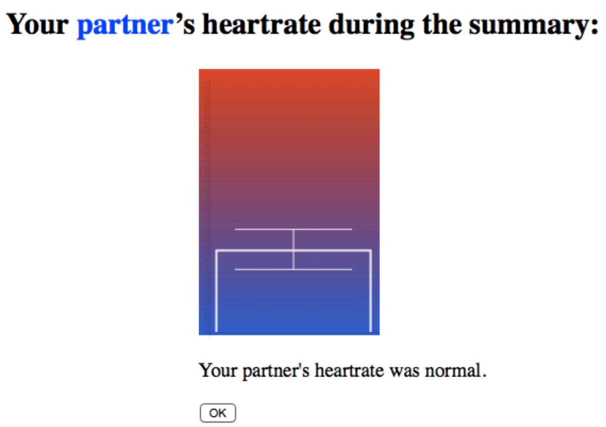

Figure 2. The heartrate visualization. After viewing the results of the previous round, subjects were presented with a graph of what they believed to be their partner's recent heartrate.

Viewing information about an anonymous partners' elevated heartrate should increase uncertainty about the interaction, leading people to protect themselves against potential losses. As described in more detail in the experimental methods below, individuals have two very different ways to respond to increased uncertainty about their partners' behavior in the repeated trust game: by reducing the amount they entrust to their partners, or by decreasing their willingness to cooperate [4, 7]. The first option to decrease the amount entrusted to the partner reduces risk (e.g. less money is at stake), but also decreases potential earnings since additional money is earned by having points returned after entrusting to one's partner. The second behavioral option is to decrease the amount of cooperation with one's partner. This second option protects one from a (potentially) non-cooperative partner, regardless of the amount that has been entrusted. We predict that individuals will use both methods to protect themselves from uncertainty when they view elevated versus normal heartrate information about their partner.

Hypothesis 3: When individuals believe that their partner has an elevated heartrate in iterated, uncertain social interactions, they entrust less compared to those who believe that their partner has a normal heartrate.

Hypothesis 4: When individuals believe that their partner has an elevated heartrate in iterated, uncertain social interactions, they cooperate less compared to those who believe that their partner has a normal heartrate.

Methods in Controlled Experiment

Our sample was undergraduate students recruited from the population of a large west coast public university. We contacted potential participants via email from a voluntary experimental subject pool. All participants expected to be contacted to participate in a social research study at some point during the semester, and they knew that they would earn between $15-30 during this one-hour study, depending on their choices during the experiment. Forty-two participants (42) completed the experiment, 30 women and 12 men. The mean age of participants was 21.

Upon arrival, participants were guided to an individual desk with privacy walls. After signing an informed consent form, participants read written instructions on the computer which explained that they will have the opportunity to interact with a single partner for many rounds in order to examine decision making in social situations. Participants were also told that we will collect pulse (heart rate) information at designated times during the study using a simple pulse monitor that was connected to the laptop computer.

Experiment Design

We operationalized an uncertain social interaction situation using the Prisoner's Dilemma with Dependence (PDD) game [4]. The PDD game allows individuals to control the amount of risk that they want to take with their partner by choosing how many points to entrust, followed by a second decision to either keep or return whatever has been entrusted by their partner. Thus, the PDD game separates trust behavior (choosing how much to entrust to a partner) from cooperative behavior (choosing to return or keep that which was entrusted by a partner).

In each round of the PDD game, participants were given an initial endowment of 10 points. Each participant decided whether to entrust any number of points to their partner, from zero to ten. Then, participants found out at the same time whether their partner had entrusted them with any of their own points, and if so, how many. Next, each participant decided whether to keep the points entrusted to them (defection) or return them (cooperation). The participants could not return only a portion of the entrusted points, only all or none of them. If the points were returned to the partner, they were automatically doubled in value for that participant.

After all participants made decisions about returning or keeping any points that had been entrusted to them, they were then asked to place their finger on the heartrate monitor for a few seconds in order to get a pulse reading (see Figure 1). Participants then viewed the summary of point calculations for the round. Subsequently, participants viewed a visual display of the partners' recent heartrate (see Figure 2).

The final point calculation for the round included any of the initial allotment of points remaining after the trust decision, plus and points that the participant kept from their partner if they decided not to return them. In addition, players received points for any entrusted points that their partner returned, which were doubled in value.

Participants believed that they were interacting with other real people, and this perception was enhanced by having 12-16 participants at separate computer terminals in the same large room during each experimental session. However, we controlled the trust and cooperation behavior of the "partner" by using a simulated computer actor. As a result, no one in the study actually interacted with another human partner.

The simulated actor was programmed to always begin by entrusting one point on the first round, and then randomly entrust up to one point above or below whatever the partner entrusted on the previous round. In addition, the simulated actor was programmed to always cooperate (i.e., return the points that were entrusted by the partner). Thus, the simulated actor was designed to reciprocate the entrusting behavior of the human participant on each round, and always cooperate no matter what the human participant chose to do. The participants completed 20 rounds of the PDD game, but they did not know how many rounds they would play in order to eliminate end-game effects.

After all rounds of the PDD game were completed, participants answered a short post-questionnaire in order to assess their attitudes and beliefs about their partner. This questionnaire included the same 7-point Likert-style response questions as the vignette study (1 = strongly disagree, 7 = strongly agree) about the partners' beliefs about the partners' anxiety ("my partner is anxious" and "my partner is calm").

As a manipulation check on the perceptions of the simulated actor's behavior, we also asked questions about the partners' game behavior ("my partner is trustworthy" and "my partner is cooperative"). Finally, we supplemented our quantitative measures with two open-ended questions: "How would you describe your partner?" and "What, if anything, did heartrate tell you about your partner during this experiment?"

At the end of the study, participants were debriefed on the true nature and intent of the experiment, and they were paid between $15-30 based on their actual point earnings during the game. The entire study lasted one hour.

Experimental Manipulation

To assess the effect of interacting with a partner with a high heartrate versus interacting with a partner with a normal heartrate, we controlled the heartrate information that participants saw about their partner after each round of the experiment. This created our two-condition study design: always normal heartrate (NH) and always elevated heartrate (EH).

LAB-BASED TRUST EXPERIMENT RESULTS

Our two behavioral hypotheses (H3 and H4) predict that participants in the elevated heartrate (EH) condition will exhibit lower trusting and cooperative behavior compared to those in the normal heartrate (NH) condition. The average points entrusted by participants in the EH condition ($M = 7.5$, $SD = 2.18$) was not significantly different than the NH condition ($M = 7.6$, $SD = 2.28$), $t = .14$, p=n.s, one-tailed test. Thus, individuals entrusted points to their partners at approximately the same level in both conditions (Figure 3). Hypothesis 3 is not supported.

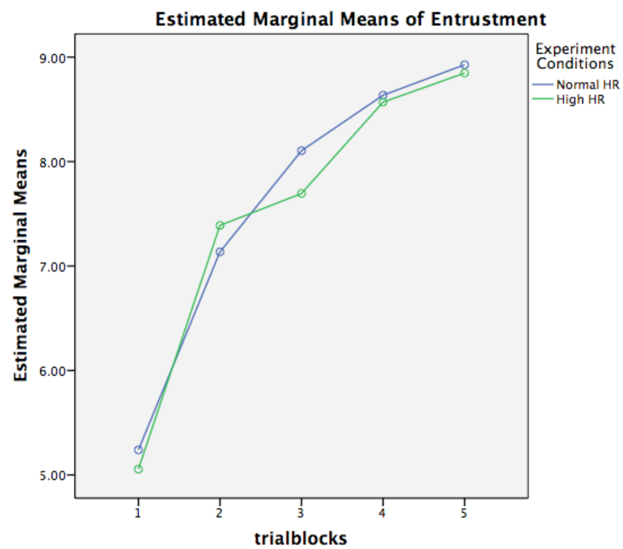

Figure 3. The number of points subjects entrusted to their partners in the elevated (green) and normal (blue) heartrate conditions over time.

We found that the average cooperation rate in the EH condition ($M = .70$, $SD = .38$) was statistically significantly lower than the NH condition ($M = .88$, $SD = .27$), $t = 1.77$, $p < .05$, one-tailed test. Importantly, this result shows a medium practical effect size (Cohen's $d = .53$), indicating a meaningful real world difference. On average, those in the normal heartrate condition cooperated 25% more than those in the elevated heartrate condition (Figure 4). Hypothesis 4 is supported.

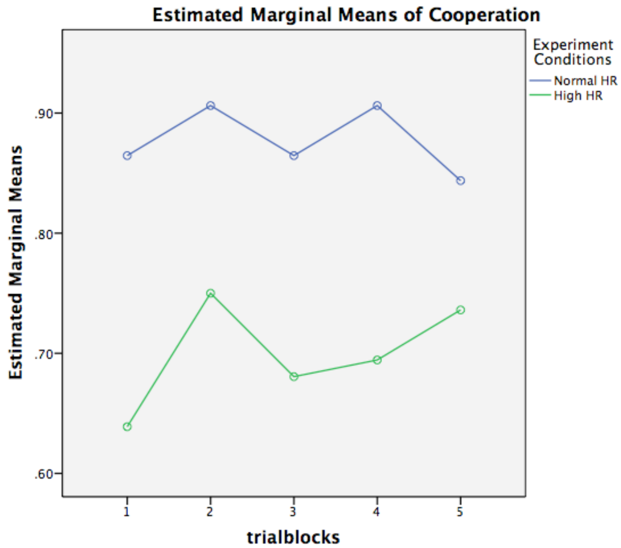

Figure 4. The rate of subjects' cooperation over time with partners who had a consistently normal hearate (blue) and partners who had a consistently elevated heartrate (green).

We also have the opportunity to re-examine Hypothesis 1 (attributions about the partner) in the lab study. We found an overall strong, statistically significant effect and medium practical association between attributions and experimental condition ($F(4, 37) = 6.8$, $p < .0001$; Wilk's lambda = .58, partial eta squared =.42). Turning to the individual outcomes, we find that perceptions of the partners' anxiety is significantly higher in the EH condition ($M = 3.67$, $SD = 1.68$) compared to the NH condition ($M = 1.96$, $SD = 1.08$), $F(1, 40) = 30$, $p < .001$; partial eta squared = .29. Furthermore, participants rated their partners as significantly more calm in the NH condition ($M = 6.17$, $SD = 1.05$) compared to the EH condition ($M = 4.56$, $SD = 1.58$), $F(1, 40) = 26.7$, $p < .001$; partial eta squared =.28. On the other hand, we found no statistically significant differences for perception that the partner is 'easily upset' or that the partner is 'emotional' (p = n.s.). In sum, we find strong statistical and practical differences in perceptions of both anxiety and calmness, but no statistical or practical differences in how emotional or easily upset one perceives the partner to be in the two experimental conditions. Given the significant omnibus test and significant results on two of the 4the individual outcomes (1a and 1b), Hypothesis 1 is partially supported in the laboratory study.

Manipulation Checks

Since we designed the simulated actors in both conditions with trusting and always-cooperative behavior, we did not expect participants to rate the simulated actors differently in terms of the focal behaviors of cooperativeness and trustworthiness between experimental conditions. This is a critical manipulation check, since we actually need to rule out any perceived effect of the simulated partners' behavior in order to establish that the primary treatment (heartrate of partner) had an effect on the human participants' behavior.

The omnibus test of difference in perceptions of the trustworthiness and cooperative behavior between conditions was not significant ($F(2, 38) = 2.58$, $p = .10$; Wilk's lambda = .88, partial eta squared =.12). Indeed, we found no significant difference in perceptions of the partner's cooperativeness ($F(1, 40) = .12$, p = n.s., partial eta squared = .00) or perceptions of the partners' trustworthiness ($F(1, 40) = 3.15$, p = n.s., partial eta squared = .07). Thus, as we would expect, individuals did not indicate significant behavioral differences for the trusting, cooperative simulated actor (which was programmed to behave exactly the same in both conditions).

Qualitative Results

At the end of the post-experiment survey, participants were asked to evaluate their partner, and to describe what, if anything, their partner's heartrate told them. Participants in both normal and high heartrate conditions generally described their partner as being "nice" and "fair."

About two thirds of participants in both groups self-reported that their partners' heartrate told them nothing, or not much, about their partner. Of those who reported that heartrate was informative, participants in the normal condition felt their partner's heartrate showed a mental calmness, or perhaps even apathy.

"My partner is emotional-stable"

"They were either really chill, or didn't care about the game whatsoever."

In the elevated heartrate condition, several participants reported that the heartrate signaled nervousness, or anxiety. Some mentioned explicitly that their partner's elevated heartrate engendered a lack of trust in their partner's desire to cooperate. When asked what partner's heartrate indicated:

"they were nervous or thinking about tricking me"

"whether he/she cheated"

"It reflected whether they were anxious or not about their decision, the lower the heart rate the more they trusted me."

Only one subject attributed the heartrate to sources outside of the situation itself.

"My partner's heart rate was elevated the whole time, most students are stressed so that might be why."

Interestingly, one participant appeared to see a relationship between their decisions in the game and their partner's heartrate.

"When I was "mean" and did not return points, the heartrate went up."

Importantly, the partners' behaviors were programmed to be identical in both conditions; only their displayed heartrate differed between conditions and the heartrate was always consistently “elevated” or “normal” depending on condition. It is interesting to imagine that this participant saw what they expected to see; in this case, that their uncooperative game activity resulted in a directional change to the partner’s heartrate, and that the random activity of the instrumented signal met with their expectation to produce this effect.

DISCUSSION

We began this investigation by asking how biosignals might influence assessments and behaviors in uncertain social interactions. The results of our two different empirical studies provide some specific insights, while also raising some additional questions about this complex area of human-computer interaction and technology-mediated communication.

The vignette study focused on a shared, presumably enjoyable social meeting between acquaintances (watching a movie together). As described in the vignette, this constitutes a one-time interaction in which the participants are trying to infer attitudes and potential behaviors with very limited information, including a single biosignal (heartrate). We found that elevated heartrate is associated with more negative emotional attributions around anxiety and lack of calmness. However, in our qualitative analysis of user interpretations, we found that participants often inferred that elevated heartrate was a token of their acquaintances’ honesty, and that normal heartrate was sometimes viewed as suspicious. These findings help to explain why we do not find support for our second hypothesis: contrary to our initial expectations, elevated heartrate is not interpreted as meaning that the partner is any less trustworthy or reliable; rather, elevated heartrate actually acts as evidence that the acquaintance is *trying* to get to the meeting place on time, and that he or she seems to actually care about being late.

Our lab-based study created a different context of interaction (repeated trust and cooperation decisions) with different uncertainties and risks (real money was at stake). In this context, we found that individuals were less likely to cooperate with partners who had consistently elevated heartrates compared to normal, even though these partners were always highly cooperative and trusting. We did not find any evidence that individuals entrusted less to these individuals. Indeed, our manipulation check confirmed that individuals viewed their partners as highly trustworthy and highly cooperative, regardless of their heartrate. Why would we observe lower cooperation but not lower entrusting behavior in the elevated heartrate condition?

We believe that the answer to this question lies largely in the qualitative results in the lab study, as well as in the consistent support for Hypothesis 1 in the vignette and lab experiments. Specifically, we know that individuals view their partners’ elevated heartrate as a signal of heightened anxiety and lack of calmness (H1). But, in the context of the trust game’s repeated interactions, participants indicated through their qualitative responses that elevated heartrate could be a signal of imminent deceit. If subjects suspect their high-heartrate partner of uncooperativeness, they must find a way to mitigate their potential risks. As we originally predicted (H3), participants could entrust less to their partners, but this would curb their earnings in the game and send a direct signal about a lack of trust before the decision to return or keep (i.e., cooperate or defect). So, players instead curb their risks by continuing to steadily entrust points to the partner, but cooperating less frequently as their concern about the partners’ duplicity grows over time. Whether this is a good long-term strategy or not is unclear, since uncooperative behavior leads to higher monetary rewards within a single interaction, but also sends a very strong signal to the partner that may prevent further advantageous recompense in future interactions.

Overall, we find that the meaning of an elevated heartrate varies depending on the context in which the heartrate is shared. In the survey experiment, high heartrate tended to be associated with perceptions of honesty; in the trust game, elevated heartrate was associated with decreased cooperation. Such differences were observed even though subjects in both experiments indicated that elevated heartrate signaled anxiety and lack of calmness.

LIMITATIONS

Our vignette experiment examined a single scenario, and part of what our larger study shows is that the context of interaction can affect the social interpretation of biosignals such as heartrate. Thus, even with the clear advantages of the multi-method approach of this study, we still have a limited picture of the range of theoretically important contexts in which individuals may observe and interpret biosignals about others.

The vignette study took place online, and used text-based answers. We could have missed the sorts of rich contextual cues that might be captured by live interviews. Furthermore, the internet presents a wide array of distractions to survey-takers, and our survey was not able to detect the participants' attention on the task (i.e., we could not detect whether the subject was switching between tabs in their web browser, or taking breaks during the survey), nor did we monitor how long subjects spent filling out the survey.

Our lab-based behavioral experiment was a controlled, study that prioritizes high internal validity at the expense of broader generalizability and ecological validity. This research paves the way for continued work that could further validate and replicate these findings through field experiments using current and upcoming biosensing devices.

Given these methodological limitations, we do not make any strong claims about the generalizability of heartrate information, trust, and cooperation behaviors in substantially different contexts. However, the findings of the study do motivate further study and verification in more ecologically valid situations, with instrumented devices such as the smartwatches that inspired this investigation in the first place. Furthermore, our study was designed to only examine a very specific type of social interaction (trust and cooperation) under conditions of uncertainty, with unknown, fixed partners. Many of the real-world situations that are of interest to many include known partners, and more complex social interaction situations.

IMPLICATIONS FOR DESIGN

The meaning of a heartrate varies depending on the social context in which it is displayed. Its effect on behavior in any given situation is far from obvious. Emerging and existing technologies such as the Apple Watch do not specify when users should share their heartrate, and this open-endedness creates exciting new possibilities for technology-mediated social interactions. But, revealing even low-level data about a user's physiology could present opportunities to read unintended cues about others' emotions, mood, and state of mind. As the findings from our lab experiment demonstrate, these cues can sometimes lead to negative social behaviors, such as uncooperativeness. In other situations, like the scenario described in our vignette, biosignals could lead to positive social assessments, such as believability and authenticity. In either case, designers must investigate interfaces that expose these signals in a variety of social contexts, evaluate potential social interpretations, and take measures to preempt erroneous interpretations that could affect social behavior.

Crucially, this work also indicates a potential divergence between what biosignals mean to people *in context*, and what they might mean to algorithms designed to analyze and interpret such signals as usable information. As an increasing number of algorithms attempt to decode empirical meanings from physiological signals, we must be aware that algorithms based on physiological signals could be at odds with our everyday understanding of what these signals mean. Designers should be aware that transmitting low-level data (e.g., a high level interpretation with optional "raw" readings) could enable users to create counter-intuitive interpretations that run counter to whatever algorithmic or empirical meanings these signals might have.

Finally, our experiments show promising evidence for the effect of biosignals on attributions of character, mood and behaviors, but do not make clear what precise mechanisms are responsible for the interpretations we observed. On one hand, the biosignal (heartrate) we showed to the participants appear to signal anxiety, and other aspects of mood. On the other hand, it is unclear whether the behaviors we observed (such as lower cooperation) were caused by the interpretation of this specific biosignal (heartrate), or its visual representation in our study's interface. Is there something special about heartrate that makes people interpret it this way, or would any "elevated" versus "normal" biosignal elicit similar interpretations? Determining what *about* biosignals give rise to social interpretations is a clear priority for those who design biosignals into devices and interactions, as well as an obvious next step for future work.

CONCLUSION

This work highlights the complexity and contextual variation in interpretations of heartrate when these signals are transmitted between people. We have shown that heartrate is a richly contextual social signal, the subject of both particular situations, and individual interpretation. The present study represents an initial examination of two different types of uncertain scenarios. We find strong empirical evidence for attributions such as anxiety from elevated heartrates, but also strong differences in how this anxiety is interpreted in different contexts. Our lab study also provides clear evidence that the biosignal of elevated heartrate can lead to at least some negative behaviors towards others (non-cooperation) depending on the context of interaction.

Our experiments provide evidence that interpretations of biosignals from sensors (such as wearables) can affect social attributions and behaviors towards others. Nevertheless, many questions persist regarding the specific causal mechanisms between how biosignals are shared, which biosignals are available, and the relevant attitudes and behaviors in a given context. Future work should continue to investigate how various biosignals shared through new wearable and emerging implant technologies yield interpretations in different social interaction and decision-making contexts. Future work should also investigate the mechanisms by which these interpretations arise. Last but not least, we believe that a clear logical next step is to conduct field experiments in real-world scenarios in order to increase ecological validity in this line of inquiry.

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