Supporting Social Interactions with an Expressive Heart Rate Sharing Application

FANNIE LIU, LAURA DABBISH, and GEOFF KAUFMAN, Carnegie Mellon University

The present work explores the social dynamics of *expressive biosignals*: leveraging wearable technologies to introduce sensed physiological data as a means of clarifying the emotional or psychological processes underlying our subjective experiences. We developed an Android application that linked to a wearable heart rate sensor and allowed for the direct sharing and real-time broadcasting of users' heart rate via text messaging. We deployed this application in a two-week field study to investigate the contextual triggers, perceptions, and consequences of users' sharing behaviors. The study (N=13) utilized a combination of Experience Sampling Methodology (ESM) and qualitative interviews to discover the situations in which users were more or less likely to share their heart rate with contacts, and the subsequent interactions that occurred after sharing. The results revealed that participants used heart rate sharing as a means to express emotions and provide daily updates, as well as simply a novel and playful form of communication. They reported a variety of communicative consequences of their sharing as well as specific logistical and psychological barriers to sharing. The implications of these results for the design of expressive biosignal sharing systems for supporting positive social interactions are discussed.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Empirical studies in ubiquitous and mobile computing**;

Additional Key Words and Phrases: Wearable sensors, physiological signals, heart rate, psychological states, interpersonal communication, experience sampling

ACM Reference format:
Fannie Liu, Laura Dabbish, and Geoff Kaufman. 2017. Supporting Social Interactions with an Expressive Heart Rate Sharing Application. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 77 (September 2017), 26 pages.
DOI: http://doi.org/10.1145/3130943

1 INTRODUCTION

The growing proliferation of wearable sensors that measure biosignals has begun to open new doors for leveraging the real-time measurement of activity such as heart rate, skin conductance, and brain activity, to improve our daily lives. While major inroads have been taken to investigate the implications of physiological sensors for intrapersonal outcomes, such as health management, we are only beginning to see a glimpse of the potential for the *sharing* of physiological data in interpersonal, social contexts. For instance, step tracking devices such as the FitBit have enabled users to engage in social fitness competitions, while heart rate-sensing smartwatches like the Apple Watch have introduced haptic heartbeat sharing. As new modes and means for sharing and understanding our data emerge, it becomes increasingly critical to understand the implications of revealing our biosignals to

This work is supported by the National Science Foundation, under grant 0943159 and grant 1205539.
Authors' address: Human-Computer Interaction Institute, School of Computer Science, Carnegie Mellon University; 5000 Forbes Ave., Pittsburgh, Pennsylvania 15213.

2474-9567/2017/9-ART77 $15.00
DOI: http://doi.org/10.1145/3130943

others. What are the social and psychological consequences of the ability to share our physiological data? How can we inform system design and policy that account for people's preferences and help them become informed participants in the use of physiological sensing systems?

Users of ubiquitous technology already share sensed data such as location and activity streams with others, in order to help them communicate and connect with each other [14, 38, 46, 52, 56]. Shared biosignals similarly have the potential to support interpersonal communication. For instance, biosignals such as heart rate are known to change with our mental states, and have been used in the field of Affective Computing to predict and reduce moods such as stress and frustration in order to increase well-being [9, 23, 25, 37, 49]. Our affective states inherently provide social information about our needs, attitudes, and intentions [28, 57]; thus, biosignal-based affective technologies could provide new ways to convey this information and support social interactions. By expressing ourselves with biosignals, we have the potential to communicate our subjective experiences, and ultimately better understand and connect with one another. However, little is known about when, to what extent, and with whom individuals are likely to want to share their biosignals.

The present work explores one specific implication of ubiquitous physiological sensing technologies: the opportunity they afford for sensed and shared *expressive biosignals* to serve as social cues in communication contexts. Given the relative novelty of expressive biosignals, and the little empirical work that has investigated their social impact, we take a broad, exploratory approach to better understand how individuals would utilize and respond to a system that allows for the real-time sharing of their physiological responses. Using a combination of Experience Sampling Methodology (ESM) and semi-structured interviews, we investigate users' sharing patterns, including the contexts most likely to trigger or inhibit sharing, motivations underlying sharing decisions, and the communicative and interpersonal consequences of those decisions. We contribute a study that reveals how people share their heart rate through their natural communication channels, finding that heart rate can be used for interpersonal expression of emotion, daily activities, and playfulness, depending on contexts and relationships between users. We present a set of design implications based on our findings that suggest new directions for the development and integration of expressive biosignal systems into social interactions.

2 RELATED WORKS

2.1 Biosignals Sharing Systems

A number of systems have been built to sense and monitor biosignals; however, most of these systems have focused on applications for individual use. For instance, popular commercial wearable heart rate monitors, such as the Fitbit or Mio watches, and several research systems have used heart rate to support fitness and physical health [20, 44, 47, 54]. Affective Computing research has expanded biosignals to social applications (in addition to health), detecting emotional and psychological states for social skills training and virtual tutors [4, 12, 13, 32, 45]. However, these applications still target individual understanding and monitoring of physiological data.

Few works have investigated biosignals systems that allow for sharing in social and communicative contexts. These include systems for supporting interpersonal relationships [42, 53, 61] and collaboration [55], increasing interactivity and encouragement in physical activities such as marathons [10, 43, 60], and facilitating engagement in presentations and entertainment [17, 22, 50]. All of these systems focused on very specific use cases and events, and were tested over short periods. Solvák and colleagues sought to build on these prior efforts by investigating biosignals sharing in a more natural setting over a longer period of two weeks. They deployed a technology probe (a laptop that provided visual and aural feedback of heart rate) in the homes of five couples and analyzed their reactions to the probe, finding that heart rate was used as information about emotional states and fostered connection between household members [51]. A recent study by Hassib and colleagues expanded this work by going beyond couples' homes and deploying HeartChat, a mobile heart rate chat application, in the wild with seven pairs of close friends or partners. They similarly found that heart rate sharing was able to foster connection

and awareness, and that heart rate acted as both an emotional and contextual cue [21]. However, in both of these past works, participants had limited control over sharing, and described situations in which they might not be willing to share heart rate because it was "too personal," awkward, or not understandable. Authors from both works suggest that sharing one's heart rate could thus potentially undermine impression management.

The present work furthers this line of research by deploying a heart rate sharing system on users' mobile phones in order to understand the everyday contexts in which users are most willing or unwilling to share their heart rate. Our system prompts users to make a decision about sharing in order to give them control over when, with whom, and how to share their heart rate with others. Additionally, sharing is conducted through existing messaging applications in order to provide a natural way through which heart rate can be communicated. Our work allows us to explore heart rate sharing at a deeper level, by investigating not only the contexts in which people would be willing to share their heart, but why they might share or not share:

RQ1: When and why would people be willing or unwilling to share their heart rate with others?

2.2 Social Meaning of Heart Rate

Past research has shown that biosignals are inherently ambiguous and open to multiple interpretations [26], which could subsequently affect the way they are shared. For the purposes of this study, we focus on heart rate, which people tend to associate with underlying emotional and psychological states [51], yet is known to elicit diverse perceptions of others depending on the context. For instance, Merrill and Cheshire demonstrated that an individual's elevated heart rate is typically associated with negative mood, such as being upset or anxious, which can affect how others trust one another, depending on the situation and relationship with that person [39, 40]. In addition, the heart has been associated with feelings of closeness—for instance, the sound and feeling of one's heartbeat are both considered intimate cues [27, 61]. Solvák and colleagues suggest that heart rate sharing could even be seen as a form of emotional self-disclosure, which may only be desired between individuals who have a close relationship [51]. Altogether, these works suggest that the relationship between individuals and the context in which heart rate is accessible plays a key role in determining how heart rate is interpreted and understood by others with whom it is shared, and subsequently how it can be meaningfully expressed through sharing. Our research extends these works by investigating heart rate sharing in a breadth of contexts, giving users the opportunity to decide if and how they want to share to others, as well as how sharers and recipients alike manage or resolve the ambiguity of heart rate. We thus explore the following research questions:

RQ2: How can people meaningfully express their heart rate to others?

2.3 Sharing and Ubiquitous computing

Though research around biosignals in ubiquitous computing tends to focus on individual monitoring, several works in this field have explored the sensing and sharing of other types of user data. For instance, a number of researchers have investigated preferences and practices around location sharing [38, 52, 56], including sharing behaviors based on hypothetical ESM requests from contacts to share location [7], and willingness to share with different types of contacts [62]. Other ubiquitous systems have been built to record and share streams of user activity. Ubiquitous healthcare, for instance, is a growing field with multiple areas of application, including activity tracking of elderly people to inform physicians and family of their daily life activities and physiological states [15, 19]. Systems that track and share personal data, particularly physical activity, through social awareness streams like Twitter are also commonly used to connect with friends and family [14, 46]. Some systems have also monitored and publicly displayed user activity levels for the support of collaborative tasks and work

environments [31, 59]. However, many of these systems focus on individual sharing behaviors and preferences, and have generally not explored the interpersonal consequences and interactions that might result from sharing.

Our work expands on past work on sharing user data ubiquitously by investigating the sharing of physiological data—specifically heart rate sharing on mobile phones in everyday contexts. Further, we consider not only users' sharing behaviors, but also how sharing affects their subsequent interactions with others with whom they share:

RQ3: What are the interpersonal consequences of sharing heart rate with others?

3 METHODS

To explore our research questions and understand heart rate sharing *in situ*, we built an Android application that prompts participants to share their heart rate. We conducted a study that used the Experience Sampling Method (ESM) [8, 33] to determine when, with whom, and why participants were more or less inclined to share their data using this system, as well as follow-up interviews to probe more deeply to understand users' experience, sharing decisions, and the social and communicative impact of those decisions.

3.1 Overview

The study took place over two weeks at a northeastern city in the United States. During those two weeks, participants wore a commercial heart rate sensing wristband daily during a self-defined 12-hour waking period and used our Android application. The application connected with the wristband via Bluetooth LE and prompted users to decide whether or not to share their heart rate (via the messaging application of their choice) up to ten times per day. After participants made their decisions about sharing their heart rate, they were prompted to answer brief ESM questionnaires to clarify the contexts and reasons behind those sharing decisions. The application saved participants' heart rate data, sharing decisions, and ESM responses on the participants' phones, and these data were uploaded periodically to a secure server. Participants were also required to come into the laboratory three times during the study (30-60 minutes each time) for instructions, equipment, and interviews.

3.2 Participants

Sixteen participants took part in this study; however, we removed data from three participants from all analyses. These participants either did not understand the instructions (e.g., one participant who instructed his contacts to ignore all of his share messages), had issues using the application on their phone and needed to drop out of the study, or had deleted their data from their phone before the exit interview. The remaining 13 participants included seven female and six male participants. Participant ages ranged from 20 to 54 years old (M=30.3, SD=10.5). Four participants identified as White/Caucasian, five as Asian, and four as African-American. Participants also had diverse occupations: seven were full-time students (two undergraduate, five graduate), three worked full-time, and three worked part-time. Two participants noted that they owned a heart rate sensor, including the Moto 360 and a Garmin sensor, but both stated that they rarely used it. Participants were recruited from a university participation pool, and were compensated with $50 upon completion of the study.

3.3 Procedure

3.3.1 Introduction Phase. At the start of the study, participants came to our laboratory to be introduced and instructed on participation in the study. During this introduction, participants first completed a questionnaire to specify their demographics (gender, age, and ethnicity) and describe their prior use of heart rate sensors. The questionnaire also asked participants to list their most commonly used messaging applications (e.g., default phone messaging system, Facebook Messenger, etc.) and to identify the six people they most frequently contacted through those applications within the previous week. The former was used to track which applications they would

Table 1. Participant Table (1st wave above the divider, 2nd wave below)

ID	Gender	Age	Ethnicity	Occupational Status	# Share Prompts	# Shared	# Did Not Share	# ESMs	# ESMs Answered	% ESMs Answered
71	F	20	White/Caucasian	Undergraduate Student	60	9	51	103	82	80%
67	M	25	Asian	Graduate Student	45	33	12	129	69	53%
22	F	26	White/Caucasian	Part-time Employment	48	2	46	59	51	86%
39	F	21	African-American	Undergraduate Student	15	4	11	42	11	26%
28	M	24	Asian	Graduate Student	19	19	0	72	66	92%
57	M	44	African-American	Full-time Employment	91	36	55	234	176	75%
74	M	38	White/Caucasian	Full-time Employment	32	17	15	88	24	27%
94	M	33	African-American	Part-time Employment	45	23	22	125	96	77%
36	F	23	Asian	Graduate Student	64	18	46	154	92	60%
87	F	39	African-American	Part-time Employment	63	40	23	171	119	70%
21	F	54	White/Caucasian	Full-time Employment	51	10	41	130	73	56%
60	M	24	Asian	Graduate Student	55	12	43	137	91	66%
44	F	23	Asian	Graduate Student	37	13	24	100	84	84%

likely use during the study and ensure that they would be made available through our study application. The latter was used to track whom the participants would most likely select as recipients for heart rate sharing messages. Given the novelty of heart rate sharing and the intimate nature of the heart [27], we expected that participants would primarily share their heart rate with their most frequent and closest contacts (most of the contacts listed were significant others and close friends and family). To track this information, whenever participants shared their heart rate, the application would ask them with whom among these six they shared, or if they shared with someone else (in which case, they were asked to provide that person's initials).

While participants answered the questionnaire, an experimenter installed the study application on their phones to ensure compatibility for the study (we required phones with Android versions 5.0+). Participants were then briefed about the purpose of the study and given instructions on using the application and watch. We gave

detailed instructions for sharing heart rate through the application, which included two methods: direct sharing (messaging their heart rate value in beats per minute to others), or broadcasting (messaging a URL for their heart rate live-stream to others), which we describe in detail in section 3.4. We also explained (verbally and in the consent form) which data would be sensed and collected during the study (e.g., heart rate data, activity, messages they sent related to the study), and the requisite permissions participants had to grant on their phones.

After the experimenter explained the study to the participants, they stepped through the application setup. As part of the setup, participants entered their demographic information (age, gender, height, and weight, which were used to warn participants about potentially dangerous abnormal heart rates), calendar events in which they would be interested in broadcasting their heart rate, the six contacts they most frequently communicate with, and the daily 12-hour waking period during which they agreed to wear the watch and use the application. Then, participants were asked to wear the watch for two minutes while sitting and for two minutes while walking in order to determine an average heart rate baseline for each activity. These baselines were used by the application as part of the logic for prompting participants to share their heart rate (described in section 3.4). Participants were then free to leave and use the wristband and study application for the next two weeks.

3.3.2 Trial Phase. The first three days that participants used the study application were treated as a "trial phase." This was included to help participants get acquainted with the application and acclimated to what heart rate sharing would look like during the two weeks, as heart rate sharing is not a common type of interaction that participants were expected to readily understand. During these three days, the application was in "Trial Mode," and it simulated heart rate sharing by displaying share notifications, but not giving participants the option to share. Instead, the notification would state that their heart rate was shared with or broadcast to a random person from the six contacts they listed during the Introduction Phase, but would not actually share any information with anyone else. The study was scheduled such that this phase would include weekdays and weekends (Thursday to Saturday or Saturday to Monday) in order to account for heart rate changes for different types of schedules.

3.3.3 ESM Phase. After the trial phase ended, the study application would end the "Trial Mode" and display normal prompts to share heart rate. That is, participants would have the option to say "Yes" or "No" to share their heart rate or broadcast link when the notifications arrived. If participants selected "Yes" to share, they could choose a messaging application through which to share, identify whom they wanted to share with, and decide how they wanted to construct their message. After making decisions to share or broadcast their heart rate, they would be prompted to answer brief ESM questionnaires on their phone, asking them what they were doing at the time they were notified, with whom they shared their heart rate or broadcast link (if they answered "Yes" to sharing), and why they decided to share or not share their heart rate. Participants were reminded at the end of the Introduction Phase that sharing was optional, and that they were not required to always answer "Yes" to sharing. The ESM phase lasted for the rest of the study.

3.3.4 Mid-study Phase. After one week of applicaton usage, participants returned to the laboratory for an interview in which they were asked to report their initial thoughts about their sharing experiences. We also used this interview to identify and correct any technical problems that arose in the application, and to ensure that participants had fully understood the instructions we had given them during the Introduction Phase.

During the interview, we asked participants whether they were surprised by the heart rate values that appeared in the notifications, whether there were times they thought they should have been notified (e.g., when they perceived that noteworthy changes in heart rate had occurred), and what they thought about their own heart rate. To gauge participants' heart rate sharing activity during the first week of the study, we asked if they shared their heart rate, and, if so, when, with whom, and why, as well as how they felt about sharing, how they made the decision to share, and what reactions they received. We also asked participants when and why they did not share their heart rate. We asked the same set of questions regarding heart rate broadcasts and, in addition, inquired

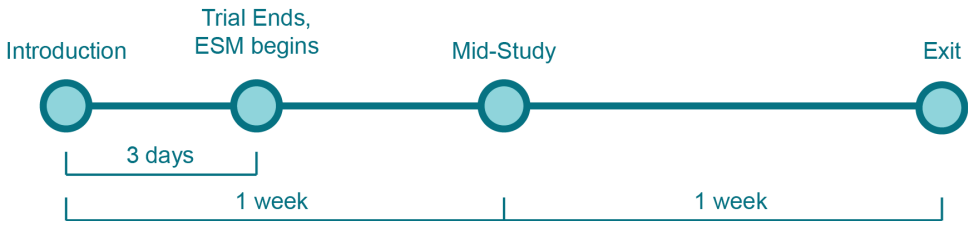


Fig. 1. Timeline of the study phases.

whether participants viewed their own broadcasts. Finally, we asked if there were times they wanted to share or broadcast their heart rate but were not able to, or if they shared their heart rate at all outside of the notifications.

3.3.5 Exit Phase. At the end of the study, participants returned to the laboratory to complete an exit interview and to return their equipment. Data from their phones, including recorded heart rates, shared heart rates, ESM responses, and screenshots of heart rate messages they shared were also downloaded at this time. The interview contained similar questions as the mid-study interview, with additional questions to gauge whether communication quantity or quality changed between participants and their contacts. We also asked participants for their feedback about the heart rate sharing application—specifically, their perceptions of its limitations, what information might have been lacking, and what they would have changed generally or about sharing.

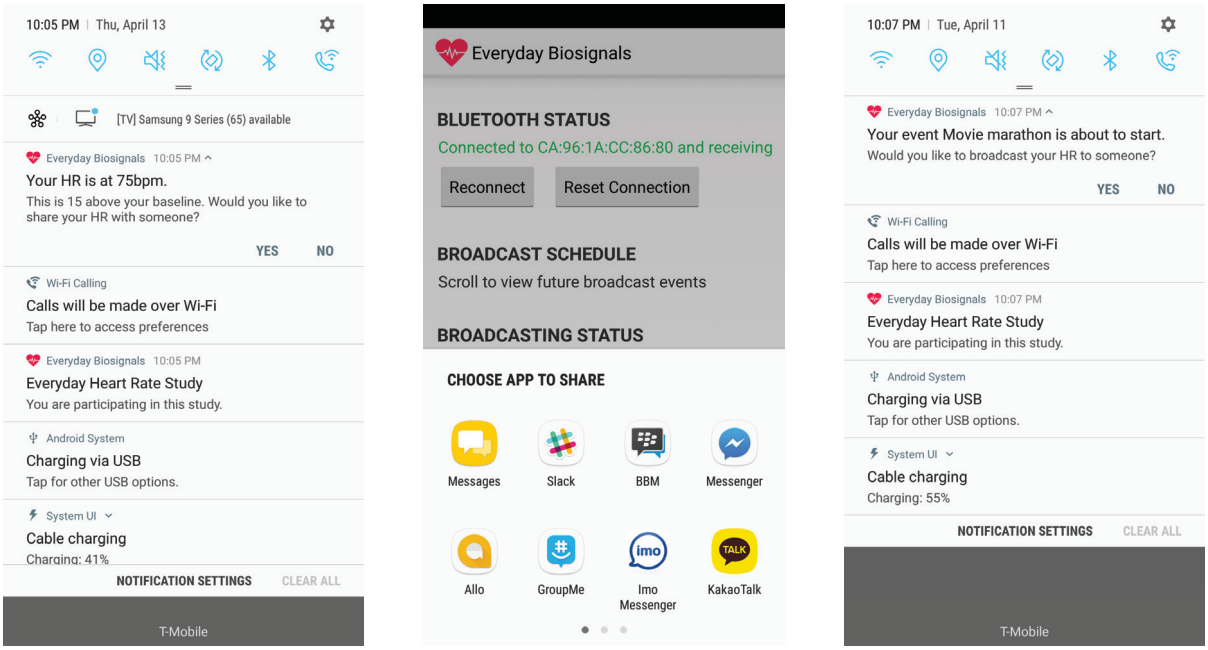
3.4 Heart Rate Sharing System

For the purposes of the study, we developed an Android application that prompted participants to share their heart rate with their contacts using text messaging applications.

3.4.1 Heart rate monitor. Our Android application connects with the Mio Alpha 2 watch [2], a consumer-grade fitness watch with a built-in optical heart rate sensor, via Bluetooth LE. We chose the Mio Alpha 2 for a number of reasons: **accuracy**, which we based on consumer reviews that compared different wristbands to chestbands, as well as prior research that used Mio technology [58]; **Bluetooth capability**: we required real-time heart rate streaming to our application in order to inform heart rate sharing; **battery life**: with the heart rate monitor continuously on, it was important to ensure that participants in the present study would only have to charge their watch at most once a day; and **user interface**: the participants would be using the watch during most of their waking hours for two weeks, thus, we aimed to reduce their discomfort wearing the technology and minimize any difficulties using it (in contrast, chestbands are known to be more accurate but would be less comfortable).

We note that the Apple Watch is an existing product that measures heart rate and allows for heartbeat sharing between Apple users. Heartbeat is shared through the Digital Touch feature, where a user can hold their fingers to the watch face to send a heart visualization and haptic feedback matching the user's heartbeat. Had we used the watch for the study, participants could have shared through this heartbeat feature, and their contacts would have been able to respond with their own heartbeat. While two-way sharing would have informed the study by helping us understand when people reciprocate sharing behaviors, we ultimately decided not to use the Apple Watch in order to have a higher level of control over the sharing interface and how the participants would interact with the application. Additionally, we wanted to avoid using existing visualizations in order to explore how users would describe their own heart rate as part of sharing.

3.4.2 Direct sharing. The application allows users to communicate their heart rate in two ways: direct sharing and broadcasting. With direct sharing, users could send a pre-scripted but partially editable text message reporting their current heart rate value in beats per minute (bpm) to their chosen contacts. In the present study, in order to



(a) (b) (c)

Fig. 2. Screenshots of application sharing notifications.

maintain the integrity of the ESM methodology, participants could make direct shares only when they received a notification to do so from the application (Figure 2a). These notifications would state participants' current heart rate and indicate how it compared to their baseline heart rate (derived from measurements taken both during the Introduction and Trial Phases), and asked participants if they wanted to share that heart rate with someone else.

If participants chose to share, they would be prompted to choose a message type (text with or without media) and a messaging application (Figure 2b). We allowed sharing through any application participants had installed that allowed text and media sharing, such as the phone's default messaging system, Google Hangouts, and WhatsApp. We opted to allow sharing through a variety of messaging applications, rather than strictly through our own application, in order to allow for participants to share with their contacts in a naturalistic fashion using their typical communication channels. The selected application would open up with a default, pre-scripted text message describing the participant's heart rate. Participants were informed at the beginning of the study that they were permitted to edit this message as long as they left the heart rate value intact and unaltered.

The application sent notifications to participants' phones up to ten times per day, with each notification spread out at least 45 minutes apart within participants' pre-defined 12-hour waking period in order to limit intrusion on their everyday lives. Notifications were displayed either at random or based on major changes in participants' heart rates (up to five notifications daily each). We included both types of notification logic in order to ensure that participants would be notified during a variety of contexts (as per traditional ESM studies), as well as during moments of fluctuating heart rate. We expected participants might be especially likely to share during the latter because of their anticipated interest in considering current activities or experiences that might have caused those

changes. We determined major heart rate changes from a random sample of heart rate values taken during the Trial Phase (during the Trial Phase, we based changes on a difference of at least 15 bpm from the Introduction Phase baselines). Major changes were considered to be any heart rate value less than the 16th percentile or greater than the 83rd percentile of the sample collected from the participant. These thresholds were chosen to ensure that participants would receive a sufficient but not onerous number of notifications during the day, which we tested using a subset of data recorded from a pilot study conducted prior to the start of the main study. In addition, we used Google's Activity Recognition API and Android's built-in step sensor to determine walking activity, during which we would instead use the walking baseline, recorded during the Introduction Phase, to determine the threshold. This helped ensure that the application would not notify participants only when they started walking, as heart rate will naturally increase during physical activity.

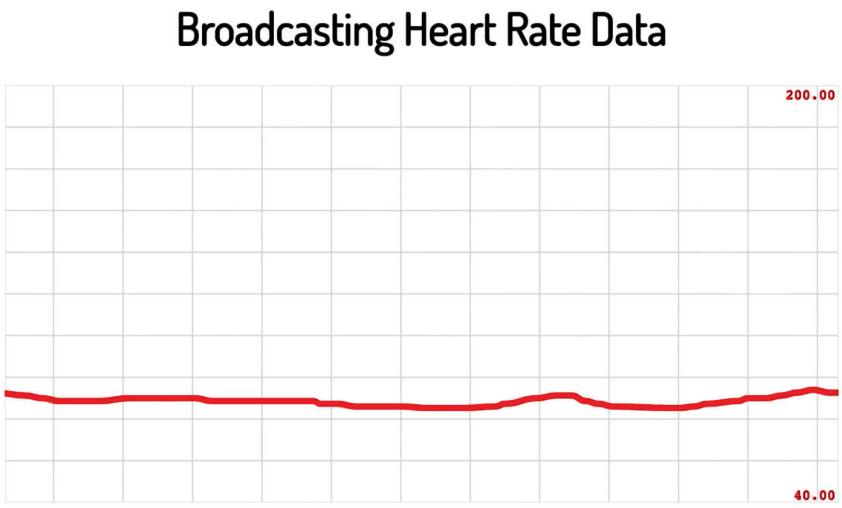


Fig. 3. Broadcast Graph

3.4.3 Broadcasts. The second type of heart rate sharing opportunity was broadcasting. Heart rate broadcasts were live-streams of participants' heart rate during designated events. Live-streams were displayed as a continuous line graph accessible to participants and selected contacts on a website that we had developed (Figure 3). The website was developed using JavaScript, HTML, and MySQL, and was hosted on an HTTPS server at our university. We decided to include broadcasts as an additional type of sharing that would offer a continuously updated, real-time display of heart rate during specific events. Past research has shown that audience members at different events, such as marathons or amusement park rides, can become more engaged with the event and its participants when they were allowed to view the participants' physiological activity [10, 50]. In this study, we aimed to clarify the range and types of events our participants would select for broadcasting their own physiological activity.

Broadcast events were created at the start of the study. During the Introduction Phase, participants each chose several events that they identified as being potentially meaningful to broadcast (e.g., watching Netflix, eating dinner with friends, dancing, etc.), and entered the details of these events (a descriptive label and the start/end time for the event) into the study application. During the study, before their specified events started, participants would receive a notification asking if they would like to broadcast their heart rate to someone else (Figure 2c). If they chose "Yes," they would be prompted to choose a messaging application for sending the website URL to

their contacts. As with direct sharing, default text was pre-populated when participants opened the messaging application; participants were permitted to edit the default text provided that they did not remove the URL.

3.4.4 ESM questionnaires. To display ESM questionnaires, our application was integrated with AWARE [16]. AWARE is an Android framework that can capture data sensed on Android phones. We used the AWARE ESM sensor to trigger questionnaires when participants chose to share or not share their heart rate or broadcast link.

3.5 Adjustments Throughout the Study

Updates to the study application were made frequently at the start of the study to address a number of technical issues (e.g., Bluetooth disconnects, scheduling errors) that emerged as participants used the application. These updates were emailed to the participants along with installation instructions and information about how to diagnose and fix these known bugs.

The study was also conducted in two waves (one week apart), with slight differences arising between the two waves as a result of our attempts to address issues that occurred in the first wave. Specifically, during the first wave, a small number of participants did not fully understand the purpose of the study and heart rate sharing after they were given the initial instructions. We clarified the instructions during the mid-study interview for these cases; however, for the second wave of participants, we updated the instructions during the Introduction Phase to include these clarifications. We also adjusted the default message in the second wave to include the heart rate difference with participants' baselines, according to feedback from participants in the first wave. Aside from these differences, the procedure was identical in all other respects for the two waves of data collection.

3.6 Analysis

We analyzed the open-ended responses from the ESM questionnaires and from the audio-recorded interviews. We took a bottom-up approach to our analysis. We performed open-coding for both the open-ended ESM responses and interviews, focusing on sharing opportunities (including hypothetical moments where participants expressed interest or intention to share) as the main unit of analysis. Codes for open-coding were first created using a random sample of responses, and then applied to the rest of the responses [48]. A similar approach was taken for the analysis of the interviews. Codes were grouped in terms of characteristics, according to what triggered or inhibited sharing, how participants shared, and participants' reflections on their sharing experiences. Themes were formed across these groups, and discussed and refined during the writing process.

4 RESULTS

Our results captured a variety of heart rate sharing instances, as expected with the use of ESM methodology. The combination of prompts triggered randomly and by changes in heart rate resulted in a range of contexts and activities for which participants made decisions around sharing their heart rate. These included more mundane day-to-day settings, engaging and entertaining activities, as well as social situations (see Table 2). Participants' moods and activities changed with each context, ultimately affecting their sharing behaviors. In our analysis, we gleaned distinct patterns of sharing motivations and behaviors, interpersonal consequences, and barriers to sharing. We discuss major themes that emerged from these patterns in this section.

4.1 Sharing Behaviors

On average, participants chose to share their heart rate 41% of the time (Table 1) over the two weeks (not including broadcasts, with the mean number of shares being 18, SD=12). Participants demonstrated different patterns of sharing according to what triggered sharing, why they shared, and how they shared their heart rate.

Table 2. Contexts from ESM prompts

Context type	What they were doing
Daily routine	Eating, cooking, cleaning, napping, lying around, driving, riding the bus, getting ready for the day, finishing the work day
Physical activity	Walking, running, biking, working out, dancing
Work	Working, studying, attending class, holding office hours, grading, volunteer work, interview prep, giving a presentation
Entertainment	Playing video games, playing in an online poker tournament, surfing the web, watching Netflix, watching TV, watching YouTube, reading, playing ukelele
Social	Talking to someone on the phone/video, meeting friends for dinner, celebrating friend's birthday, reuinion, hanging out with family, attending or waiting for meetings

4.1.1 Expressions of Emotional or Psychological States. In accordance with past research [21, 51], several participants focused on the association of heart rate with emotional and psychological states, and viewed heart rate sharing as an opportunity to convey or express those states to someone else (P71, P39, P36, P57, P22, P74, P60). Their reported sharing behaviors, as well as their desire to share in moments when they did not receive sharing prompts, illustrate this theme.

For example, several participants perceived a link between their heart rate and their experience of stress:

> *I guess I sort of thought about [heart rate] as an indicator of stress.* - P22

> *We look at a variety of things [on YouTube] and there are some political things that get me a little bit fired up. People talking very foolishly sometimes, and you sit down and want to throw something at the computer screen.... Sometimes I did, sometimes I didn't [want to share]. Sometimes I just want to express what I feel at the time.* - P57

One participant was primarily interested in sharing her heart rate during moments when she felt unable to visibly express her stress to people who were physically present or when she wanted to share her feelings of stress with remote friends or family members. This participant described two distinct situations where this was the case: facing perceived discrimination at a bar and going on a date.

> *[The bouncer] like, wouldn't let me in because he said I had an attitude. Which was like, I think that was really like stressful for me because as a black woman you're always labeled as being sassy.... I talk with my dad a lot about this...I think that's a situation I would have shared with my dad.... I think it's just, thinking about when you face issues of discrimination, how your body reacts, I think that's interesting. It's interesting because you're there and especially after you've been told you have an attitude you have to remain calm but like, you're just so worked up as well, but there's that contrast between how you feel versus what you're giving off to other people.* - P39

> *I'm one of those annoying girls where it's like I text my friends everything when I'm on a date. I feel like that would have given them information.... Like sometimes I just get super stressed on dates, and think again it's where you seem calm but you feel your heartbeat going fast. I feel like that can either be a good thing or bad thing.* - P39

Another participant desired to share her heart rate to express her emotions during moments of conflict with others. She mentioned two specific cases where she had hoped the sharing notification would come up. In both instances she wanted to let her boyfriend, as the person who cared most about her life, know how she was feeling.

> *My dad and I have sort of a rocky relationship, and we were talking and I noticed that my heart rate was elevated on the watch, and I would have sent it to my boyfriend.... Another time would be, my boyfriend and I were fighting and I noticed it was elevated, and I would have sent him that.* - P22

Participants tended to associate moments of stress with elevated heart rate and often shared when their heart rate was higher than their baseline. However, some participants were also interested in sharing when their heart rate was lower. One participant, for instance, felt that his heart rate lowered as a result of watching an emotional video, and wanted to share that with his girlfriend whom he missed. Two other participants associated lower heart rates with calmness. One shared a lower heart rate to express that she was calm to a contact who tends to worry about her. Another shared to show that she was capable of being calm in a negative situation:

> *In class, where the professor wants to make us miserable, I would like share it, "oh yeah, he wasn't successful"...I was like calm...so I sent my heart rate.* - P71

Though some participants simply wanted to express themselves, one participant was motivated to share in order to gain support from her contacts (Figure 4b). She appended text about her feelings to the default message, and sent it to friends she believed would be sympathetic towards her:

> *I think I shared two indicating that I'm feeling blue.... I'm interested in how people would react to it if I'm sharing my negative emotions. Do people actually care about me.... I was seeking comfort in a way but in a very indirect way. By sharing heart rate I'm implying that I might need help...so this is a very indirect way of sharing my emotions. So I'm interested if they can sense it.* - P36

Participants who associated heart rate with emotional changes also chose to broadcast events during which they expected to experience stress, excitement, or calmness. These included events such as participating in festivities during Holi (the Hindu "festival of colors"), taking one's children to the dentist, taking an exam, attending church, and participating in project and advisor meetings.

> *[Holi is] going to be something exciting, and my heart rate is surely going to shoot up that day.* - P60

> *It's just an event that involves the kids and it can potentially be frustrating. It's always an adventure, so you never know what's going to happen.* - P74

> *Japanese class...because it's usually a very soothing class for me.* - P36

As these cases illustrate, a number of participants deemed their heart rate to be an indicator of their current emotional or psychological state—and the sharing of their heart rate to be a means of expressing those states to close others to increase their understanding of those subjective experiences.

4.1.2 Daily Updates. Some participants integrated heart rate into their everyday conversations with their close friends and family (P71, P60, P39). These participants wanted to update these close contacts whenever there was something going on in their lives, such as a change in their current activity.

> *[I shared j]ust to let them know that I'm changing my activity, or maybe to let them know that I've woken up...or if it's too high then maybe I'm out and doing something or maybe running.... So they have a sense that I'm not at home, or if I'm at home, I'm eating and stuff.* - P60

These participants used heart rate sharing as a way to give an update that represented "small instances" of their daily lives that they were simply making "commentary" about. In these cases, participants chose to share primarily with people who typically knew and cared about their day-to-day activities, such as family members and significant others.

> *[My boyfriend] asked me to [share]... I think he asked me to because he's interested in my life in general. I thought it was fun sometimes because we pretty much know what each other's up to...so it was usually a commentary on what I was doing.* - P71

> *I think it was mostly just people who I talk to about, like, my day-to-day activities with...for example I don't drink coffee often, so people who I would tell I had coffee that day, like you know those really small things.* - P39

In one case, a participant's contact was even able to start predicting what he was doing based on his heart rate:

> *It actually served a good purpose. My mother actually knew if I was eating, because she could guess the time and the heart rate and she could sense that I was maybe eating or cooking food, so she already knew that.* - P60

For these participants, heart rate sharing became a means of providing daily updates to people they cared about. The messages they sent could replace or supplement typical updates, both when they were asked about what was going on in their lives and when they simply felt like sharing these updates. Their motivation was primarily to allow those who care about them to have insight about their daily routines, activities, and experiences.

4.1.3 Novelty. While the previous sections demonstrate that many participants shared at specific instances according to their feelings or activities, a number of participants decided to share due to the sheer novelty of heart rate sharing itself (P67, P28, P74, P21, P94, P87, P44). These participants felt compelled to share simply because they were prompted to do so and wanted to experiment with sharing as a new form of communication; thus, their shares were largely indiscriminate, triggered whenever they received a notification.

> *[I shared] just whenever I wasn't too busy doing something else.... If it was a situation where I could focus on it for a second. (Interviewer: "Why did you share whenever?") The novelty's still there.* - P74

Participants who were intrigued by the novelty decided to share to see how others would react. To them, heart rate sharing seemed "weird" and "odd" and, consequently, they were curious about how their contacts would respond to it. One participant noted that the more reactions she saw, the more comfortable she felt about sharing:

> *Especially when I first started [sharing] I was like...who would think this is least weird.... And once I did that, it built my confidence up a little.... I think the next one was [A], and I was just curious about how he would react...because he does live in another culture.... [H]e didn't have a question about what I was doing, so that kind of satisfied that.* - P21

Participants also occasionally tried to "mix it up" by sending to different contacts to see more initial reactions, especially when their previous contacts began responding to their messages less frequently:

> *Usually for the first one their reaction would be more intense or stuff like that, so I kinda wanted to switch to another person to see what people say.* - P36

> *Because other people weren't responding anymore, so I was like maybe if I send it to her she'll respond, and you know if I ask her to.* - P87

However, the novelty effect tended to wear off in the second week. During the latter half of the study, some participants reported that they habituated to sharing and, as a result, shared less often.

> *Initially it was good, but later on it just felt like a redundant thing, sharing the same kind of information over and over again. So later on, I stopped sharing.* - P44

4.1.4 Playfulness. While many participants shared simply to try out heart rate sharing, some participants viewed the novelty of heart rate sharing as a fun way to interact with their contacts (P67, P28, P74, P36, P71). They shared their heart rate whenever they were in a playful mood or found the heart rate value amusing. For instance, in one ESM response, a participant mentioned that she and her contacts "laugh about high heart rates" (P71). Another participant constructed his heart rate messages to be funny by adding images and media to it, sharing with his wife because he "knew it would make her laugh" (P74).

One participant shared often because it became an inside joke with his friend (Figure 4d):

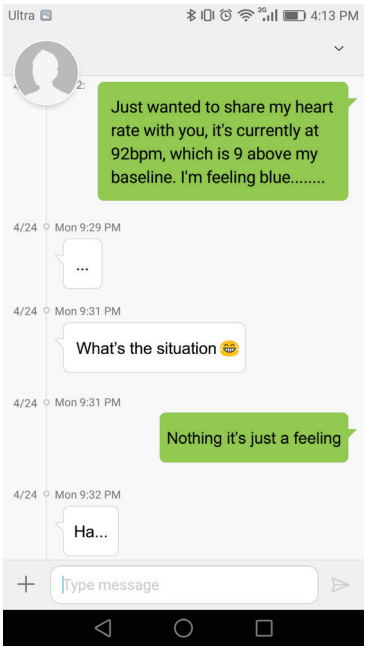
After a while it became a humor thing of sharing it with [him]...he was the guy who would always comment, "it's very high, you're going to die." - P28

Another participant chose from his list of six at random to see what kinds of funny reactions he would receive. He occasionally chose to keep an "air of mystery" during his conversations by purposely *not* explaining the data:

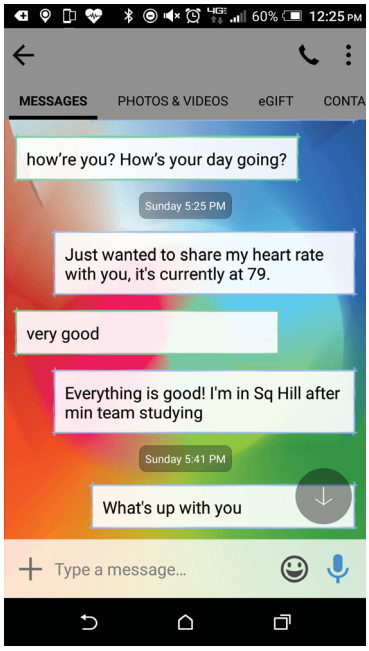
Sharing, I just did it because it was asked for me to share, or I just wanted to freak out someone by sending it. - P67

Type	Emotional Expression	Daily Update	Novelty	Playfulness
Trigger	Feelings	Changes in activity	Share notifications	Share notifications and amusing heart rate values
Motivation	Express feelings to contacts, seek support	Let contacts know about their daily activities	Try it out and see people's reactions	To make people laugh or freak them out for fun
Use of Data	Relating changes in heart rate to their emotions	Relating changes in their heart rate to what they are doing at the time	Leaving the default message	Leaving the default message for mystery or adding media for fun

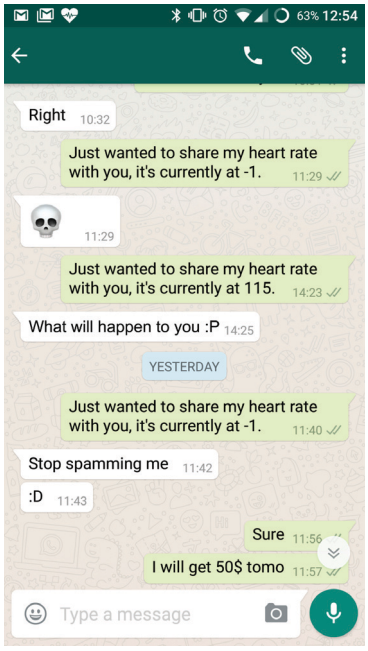
(a) Description of sharing behaviors.



(b) Emotional Expression, translated from Chinese.



(c) Daily Update.



(d) Playfulness, translated from Hindi.

Fig. 4. Screenshots and descriptions of sharing behaviors.

4.2 Consequences of Sharing

Heart rate sharing elicited a number of responses from participants' contacts. Participants described the different conversations they had with their contacts about the heart rate, which were affected by factors such as their relationship with their contacts and the ways their contacts interpreted or responded to their heart rate data.

4.2.1 Meaning-making from the Data. Most of the participants' contacts reacted to heart rate sharing with questions such as, "What is this," "Why are you sharing this," and "What are you doing?" Participants' contacts, who were not given any prior explanation about the study as context for participants' sharing behavior, were initially confused and surprised to receive unexpected notifications about the participants' heart rates. Participants realized that the heart rate value by itself may have been difficult to interpret.

> *I don't think that anyone on that list has a good concept of what their heart rate is or what that number means in context to me, like if that's my resting heart rate or whatever. So I don't mind sharing it, but I don't think they would understand it or have enough information to understand it.* - P22

As one means of countering any potential issues concerning the receipt of unexpected heart rate notifications, many participants specifically chose to share with people they believed would not need any additional explanation about what their heart rate meant or why they were sharing it. They thought that these contacts would not respond negatively to a message that appeared out of the blue or that, to others, may have seemed "weird."

> *It just never really felt comfortable with that kind of non-sequitur with anybody else...It's just different [with my wife], you don't necessarily have to explain or give any context necessarily.* - P74

> *They would understand—not understand, but know what's going on. Like everybody else might freak out, like, "what the heck is this."* - P57

However, despite these expectations, participants' messages were often met with confusion, questions for clarification, or, in some cases, very little reaction at all. One participant speculated that this was perhaps due to the fact that she did not provide enough information to explain the meaning behind her shared heart rate:

> *Maybe that's why nobody responded, because they didn't know what was happening.... I think maybe I just expected people to know what was happening around me more. I made assumptions...I thought it would give them some insight without changing the default text....* - P39

Upon realizing their contacts' initial confusion, many participants followed up on the original sharing message to provide elaborating contextual information. They would generally explain what they were doing at the time, to help their contacts understand why their heart rate was at a particular level in that moment (Figure 5a). If participants were asked why they shared, they explained that they were testing a heart rate sharing application, as per the instructions given to them for the study. Some participants also included additional media or altered the default text in order to provide more context to their contacts:

> *Most people probably never had anyone send them their pulse rate, so it's kind of just an odd thing to do. But if you do it in conjunction with something with a little more content, it kind of makes it relevant. Here's a picture of what I'm talking about versus here's a random number...just to give something to come with that dry statement of "hey, here's my pulse rate, it's high or low," so you have a picture...just something to correspond with that number or sort of illustrate it.* - P74

4.2.2 Health Concerns. Though many of the participants' contacts required more context to understand their heart rate, almost all contacts expressed concern for the participants in their initial reactions. They inferred that notifications about high or low heart rates were an indicator of potential physical health issues, and addressed these concerns to participants. A few contacts even called participants soon after they received the message to confirm their health:

> *She texted me "what's going on," but I didn't see the "what's going on." Like I said, she's like a mother figure, so when she didn't hear from me, and she sees that I'm monitoring my heart rate, like she jumped on the phone like 20 minutes later like, "I said, what's going on".... Basically I told her, "don't worry I'm not dying. It's not like I'm wearing this for a hospital or something, I'm just wearing it to wear it and I'm sending this to you."* - P94

Given that heart rate is often associated with health, some participants made sure not to share with others when their heart rate seemed too high or too low. These participants usually avoided sending their heart rate to their parents so as not to worry them.

> *When it's high I really don't want to share it with them, because they would get worried about it, so I didn't send it to my mom or dad.* - P44

In one case, a participant lied about what he was doing so that he would not worry his parents. At the time, he believed his heart rate reflected his own worries about finishing an assignment. However, having accidentally shared his heart rate with his parents at that time, he decided to instead tell them that he was running:

> *Once maybe I did share it with them and they asked me what I was doing. So I had to lie to them and tell them that I was running because I didn't want to tell them I was worried or something...Indian parents they get really worried if they feel that you are not feeling well.... So I just wanted to tell them it was nothing to worry about.* - P60

One participant, however, made the decision to share in relation to her health. During the study, she discovered that she had a heart problem (she had visited her doctor after the application notified her that her heart rate was abnormally low). This participant shared her heart rate several times with her husband, who would respond with concern and suggestions to support her health:

> *Because he was with me when it went up, and it went up really high and really low, and he was with me in the hospital...and he's with me when...stuff goes up, and is like, "why is it going up so high, you need to calm down," or, you know, "go walk away, or go talk or whatever."* - P87

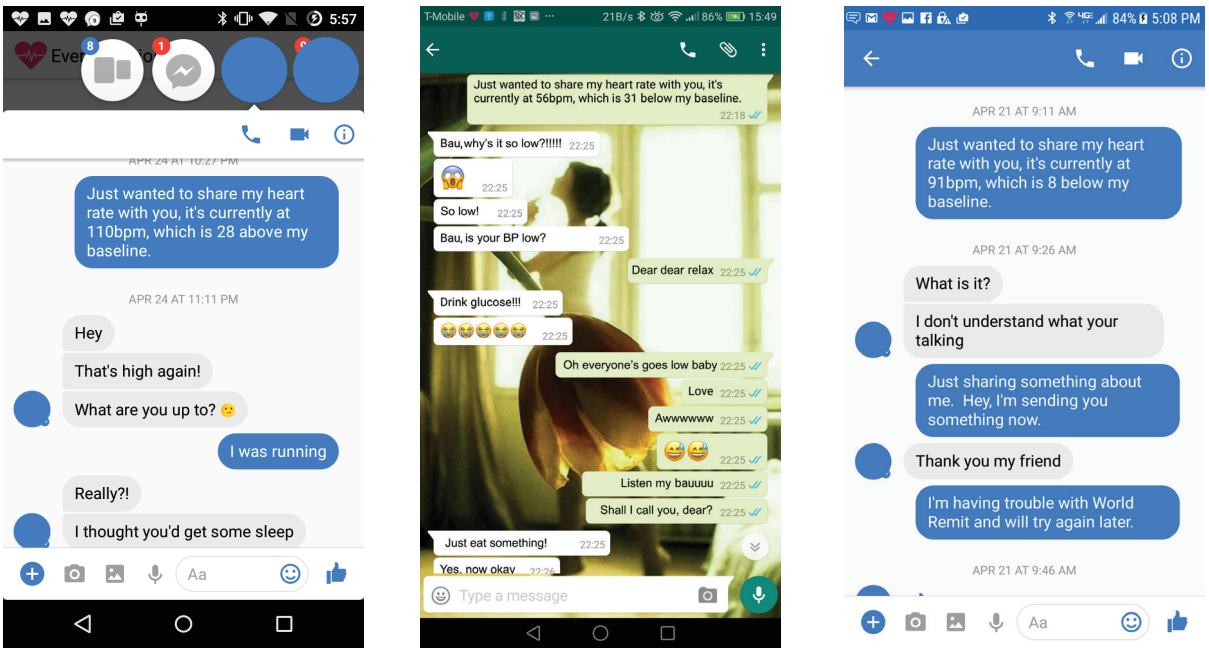
4.2.3 Opened Communication. Though most participants felt that there was no change in the quantity or quality of their communication with their contacts, two participants mentioned that sharing their heart rate helped them open up communication with specific contacts. They felt that sharing had helped them overcome some difficulties they had previously experienced when conversing with these contacts.

One participant felt that heart rate sharing was akin to revealing a part of herself with another person (Figure 5c). Thus, sharing her heart rate helped pave the way for her to have a more difficult conversation with that person.

> *Afterward, I felt I was able to talk to him about something that was kind of difficult...I kind of felt like sending the heart rate thing had opened that door a little bit.... I felt like I could talk to him about things more...like, it wasn't just a one-sided communication.* - P21

In another case, a participant felt that his communication with his grandmother had improved as a result of sharing. He believed that his prior interactions with her were very formal, but sharing his heart rate with her helped him achieve a more casual and interpersonal relationship with her:

> *I don't generally share too much with her how I'm feeling and stuff like that. It's generally a formal kind of talk that we have. But I felt that this was something really interpersonal, so I felt good. She was worried about me, she was asking me, so I told her, so we had this rapport going on. So I liked that, it was good.* - P60



(a) Meaning-making.

(b) Health concerns, translated from Hindi.

(c) Opened communication.

Fig. 5. Screenshots of sharing consequences.

4.3 Barriers to Sharing

Though participants exhibited different types of sharing behaviors, they also encountered moments where they did not want to share their heart rate. They reported certain barriers to sharing that they attributed to limitations of the system and the timing or frequency of the prompts, as well as to limitations of the heart rate data itself.

4.3.1 Logistical Feasibility. Almost all of the participants stated that a major reason behind not sharing their heart rate was that they were too busy to engage with the application and answer the share prompt. These busy moments usually occurred when participants needed to work or were involved in something that required their full attention, such as driving, playing games, or bathing their baby. Participants also missed several notifications throughout the day due to the notifications only appearing on their phone. For example, they did not always pay close attention to their phone, or they had their phone on silent when they were busy. One participant noted several periods where she could not look at her phone at all, as she worked irregular shifts at a store that required her to leave her phone in her locker during work hours.

A few participants were also limited by the schedules enforced by the application. These participants had to consider which of their contacts would be available during the waking period they had previously defined. For example, one participant, who primarily shared with his family and girlfriend in India, noted that there was a fixed period during the day when he did not share because they would not be awake. Another participant stated that he was a "night owl," and his waking period, defined as 9PM to 9AM, limited whom he could share with:

> *The way I see it—a lot of people don't put their phone on vibrate. Let it be three o'clock in the morning and I'm hitting you up, telling you that my heart rate is 97 beats per minute as you've been asleep. It's not pretty.* - P94

Many participants also missed several or all of their scheduled broadcasts. They had either failed to notice the prompt to start the broadcast before their event started, or experienced a change in their schedule and decided that the broadcast was no longer relevant.

4.3.2 Finding Interesting Moments. Another barrier to heart rate sharing was participants' desire to exclusively share interesting or noteworthy moments or events with their contacts. Though what counted as "interesting" varied per person, participants frequently evaluated whether their heart rate would be worth sharing to their contacts (e.g., whether it would open up a dialogue or elicit a response).

> *I guess it was sort of anticipation of whether this was going to elicit a chuckle, or is this going to be met with silence.... Is this funny or not, is this interesting or not?* - P74

Some participants determined what was interesting based on the perceived relevance of the heart rate and/or the context in which it had been triggered. For example, P22 shared her heart rate with a friend because it had shot up when that friend sent her a text message about wedding plans (Figure 6a). P74 shared his heart rate with his cousin-in-law after he had just parted ways with their family after a day at the park. Both participants had adjusted the way they shared by adding media or changing the text of the default sharing message.

> *The number in and of itself, I don't know how relevant it is... I have to explain what that number means to me, like my friend...I explained to her, like I didn't give her the number. I said that it was increased, because I felt like that was the important part, not so much the number.* - P22

For other participants, what was interesting depended on how they felt or what they were doing at the time. For instance, if they "felt normal" even when their heart rate was above or below their baseline, or if they didn't seem to be doing anything significant, they typically did not share their heart rate.

> *Pretty much [I shared] when I felt like there was something significant happening. Like I don't remember exactly when but a lot of times it would ask me if I wanted to share it and I was like sitting at home chilling, and I was like, there's nothing significant about this.* - P39

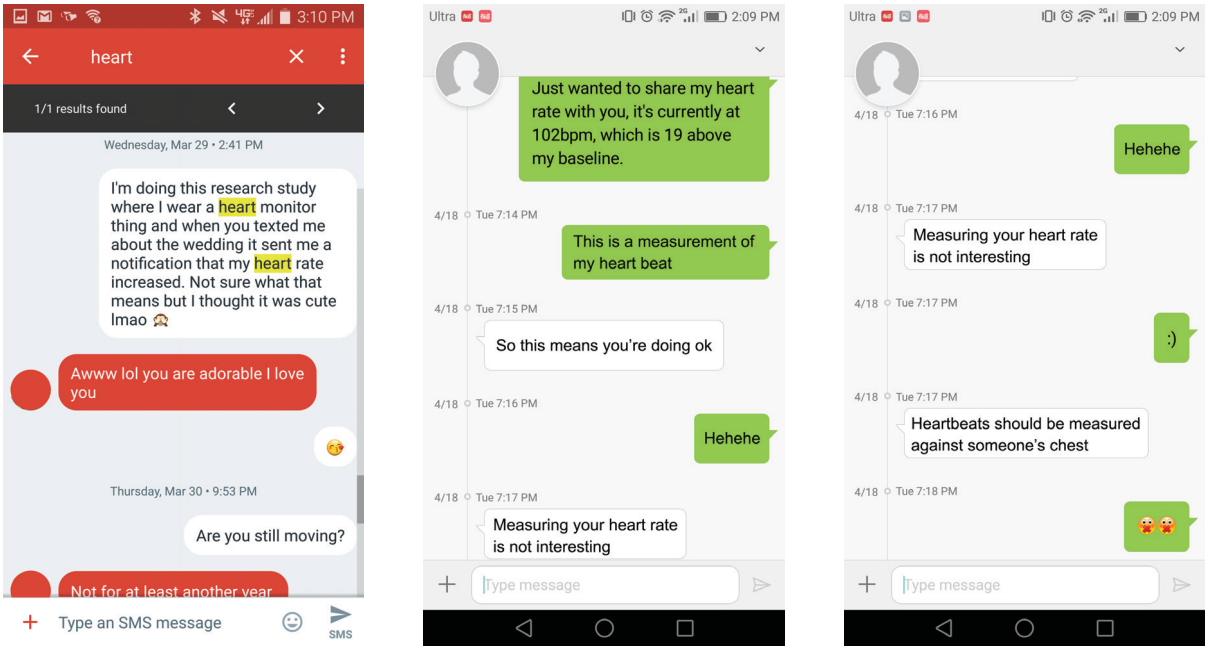
Participants similarly chose to broadcast events (or reported wanting to broadcast) when they believed their heart rate graph would show interesting fluctuations. Many participants expected this would occur during events involving high levels of physical activity, such as biking and belly dancing, or high levels of emotional intensity (as described above). One participant stated that she ended up not broadcasting because she thought it would be "boring," since there would be no interesting changes in the graph to watch:

> *It was just a flat line, really, and it wasn't doing much, and I couldn't foresee it doing much in the future, and it seemed like anyone who would watch it would watch it for five seconds and then go away.* - P22

Two participants felt that their heart rate would generally not be interesting to anyone but themselves. They believed that they would not have shared outside of the study because "nobody cares" about their heart rate, and no one else would have any use for it.

> *I don't want to know the data of someone else's heartbeat.... I don't have any use for it...what is the value if it doesn't mean anything to me.* - P67

However, one of these participants noted that while most people would not have use for his heart rate, there was a possibility that his parents would be an exception because they tend to care about *all* aspects of his life. This is similar to participants who primarily shared with their significant others because they believed that they are the ones who care the most about their lives. Thus, for some, heart rate sharing may be most interesting to intimate others.



(a) (b) (c)

Fig. 6. Screenshots demonstrating sharing barriers. **a)** Making heart rate relevant; **b)** and **c)** The conversation P36 had with her contact, implying the intimacy of heart rate (translated from Chinese).

4.3.3 Vulnerability and Intimacy. In line with previous research about heartbeats [27], some participants expressed their belief that heart rate is very intimate. Because of its deeply personal nature, they did not always feel comfortable sharing their data with others. For instance, one participant received a response from a male friend that referenced the intimacy of heart rate sharing (Figures 6b and 6c). She later hesitated whenever she shared because she did not want the recipient to interpret it incorrectly:

> *Even with my close friends, I was concerned a lot about whether I should share my heart rate with people. It's just something too intimate.... My best two friends it's fine, but yeah. Sharing with a guy, like, a male friend, I will hesitate more because heart rate is...it just indicates intimacy and I'm not sure if it's proper.... It's like flirting with a guy.... So that's why I'm concerned if I'm conveying the wrong message to him by sharing heart rate.* - P36

Some participants also felt vulnerable about heart rate sharing due to the potential to be judged by others based on their heart rate value. They felt that by sharing their heart rate, they would be giving other people too much information about their physical state or fitness level:

> *It makes you feel kind of vulnerable. Because you're basically, quite literally, sharing your heartbeat.... It's like at first when your heart beats fast people are judging me because they're like, oh you're not taking care of your heart, you're sitting down?* - P94

However, while some participants felt hesitant about sharing due to the intimate nature of the heart rate, one participant enjoyed the idea of sharing something so personal. In particular, she felt that by sharing her heart rate, she was sharing something unique to her but at the same time universal to everyone:

> *I was showing something about myself, so I kind of like that. So it was kind of fun.... Everyone's connected by having a heart and a heart rate, but whatever your heart rate is at a particular time is unique to you in that time. And it changes all the time, as you can see clearly from the watch. So it's kind of unique in that moment.... It's something personal to you but it's also something that everyone has. So it's sort of both universal and personal.* - P21

5 DISCUSSION

5.1 Supporting Interactions with Heart Rate Sharing

Participants shared their heart rates with their contacts in a variety of personally meaningful and expressive ways, demonstrating the potential for this new type of interaction to support interpersonal communication. In line with past research [51], heart rate sharing was viewed as a form of emotional self-disclosure, where participants shared as a means to express their affective states to their closest contacts and even signal to them when they were in need of support. Emotional expressions are known to be crucial to conveying information about our needs and intentions to other people, and can improve the quality of our interactions and closeness of our interpersonal relationships by increasing empathy and trust between individuals [29]. While we typically express our feelings through verbal or visible behaviors, our findings suggest that heart rate sharing can provide a new and more concrete means to detect and express our feelings based on our bodily changes. In particular, during difficult situations or moments when our subjective experiences do not match what others observe or expect from us, revealing a change in heart rate can validate the way we feel, both to ourselves and others. This is likely due to assumptions that our biosignals represent objective information about our states [51].

> *I guess I have a concept of how emotionally taxing it was for me, but to see it in numbers...that would...make it more real that that's what I experienced.* - P22

In addition to these emotional expressions, participants used heart rate to inform people about their activities in more mundane everyday occurrences. Past work suggests that heart rate can act as a implicit contextual cue [21]; our findings extend this by showing that participants will also use heart rate to explicitly signal to others how their bodies change as they go about their day. Sharing in this manner appeared to support social connectedness, helping participants keep their contacts constantly aware and in touch with their lives. One participant, whose primary contacts were in India, felt that this made heart rate sharing especially beneficial for remote communication. Research on remote communication supports this, where those in long-distance relationships tend to want to know about each other's more mundane daily moments to feel more connected [35].

Participants' sharing behaviors also led to social interactions with their contacts that encompassed a variety of topics, from meaning-making discussions to conversations about health and well-being, as well as a variety of tones, from deep and intimate to light and playful. Furthermore, while some participants who perceived their heart rate to be deeply intimate reported some level of hesitation about sharing their data, others leveraged that intimacy to initiate more open verbal communication with contacts. These findings show that heart rate sharing can open new types of meaningful interactions and conversations with others.

Taken together, our findings demonstrate that heart rate is capable of acting as a powerful new computer-mediated cue. Prior work has established that we lack access to essential nonverbal cues in computer-mediated communication (CMC), including body language and facial expressions, which can lead to depersonalization, misunderstandings, and distance between interaction partners [6, 30]. Emojis and emoticons are perhaps the most common CMC solution used to compensate for these missing nonverbal cues, particularly for expressing emotions [11]; however, these communication tools are known to elicit multiple interpretations from different

audiences [36, 41] and potentially reduce the intensity of users' emotional experience [11]. We suggest that heart rate could supplement CMC interactions as a new cue by providing information about our underlying responses to different situations, which we would otherwise be unable to visibly express. Heart rate can be used to signal our emotions, our activities and context, playfulness, and our need for support or connection with others at particular moments—features that have all been identified as significant benefits for communication technologies [63]. Additionally, unlike emojis, heart rate stems from our bodily reactions. As noted by P21, people may subsequently feel personally connected to their heart rate, while recognizing that everyone has one. Thus, heart rate may be able to provide a more "universal" (P21) cue for representing our subjective experiences, and convey an emotional intensity that may be lacking in current CMC.

Other biosignals can also reflect our bodily reactions to our subjective experiences, and thus may similarly serve as effective computer-mediated cues when shared with others. Skin conductance and brain activity, for instance, are known to change with our engagement levels, emotions, and cognitive processing [5, 18, 24, 34], and thus could also enable users to express themselves, explain their contexts, and connect with other people. With recent developments in consumer-grade wearable biosignal-sensing technology, such as the empatica Embrace [3] or the Muse brain-sensing headband [1], future work should consider investigating the sharing of these different types of biosignals and their ability to support social interactions.

5.2 Heart Rate as Ubiquitous Data

Our research demonstrates the potential for leveraging sensing technologies to introduce expressive biosignals like heart rate as a new form of ubiquitous data, which can support communication by fostering self-expression and interpersonal connection. At the same time, we find that the sharing of physiological data elicits reactions and raises issues similar to those that are evoked by the sharing of other types of ubiquitous data, such as location and physical activity. Having control over when and with whom to share heart rate was important to participants. Paralleling findings from research on location sharing, participants in the present study preferred to share their heart rate data with their closest contacts, particularly when the information was relevant to those contacts or would be interpretable by them based on shared context or information [7, 62]. Additionally, like in the case of location sharing, we found that heart rate could be interpreted differently than intended if not explained by the sender [52]. Failure of participants to explain or provide context for their heart rate inhibited their contacts' ability to understand their motivation for sharing. As in the case of activity sharing [14], heart rate receivers would subsequently respond with confusion or apathy. While these motivations may not have been clear to participants' contacts, our results suggest that participants shared for both purpose-driven (e.g., support-seeking) and social-driven (e.g., expressing interesting moments or aiming to evoke particular impressions) reasons [56]. Clarifying and supporting these different motivations, in addition to considering the other aforementioned issues surrounding heart rate as a form of ubiquitous data, will be critical for improving the design of heart rate sharing technologies. In the following section, we discuss design implications for improving these technologies for expressive heart rate sharing.

5.3 Design Implications for Expressive Heart Rate Sharing

While our findings demonstrate the social implications and opportunities for heart rate sharing, challenges and feedback described by our participants suggest important design implications for systems that enable expressive heart rate sharing.

5.3.1 Disambiguation with Context-Awareness. As the experience of many participants in the present study indicated, the sharing of heart rate data without the addition of elaborative contextual information often resulted either in initial confusion from recipients or interpretations that did not align with sharers' actual subjective experience (e.g., a concern about their health or well-being). Participants either falsely assumed that their contacts

would know or be able to infer their context or current states from the heart rate, or lacked the motivation to alter the default text to provide this clarification. Thus, it is important that sharing systems encourage and facilitate sharers' clarification of context to reduce the occurrence of crossed signals. This may take the form of visualization schemes that provide clearer connotations of a particular psychological state (and the ability to choose between alternative schemes), the provision of tools that link physiological responses to disambiguating context clues (e.g., kinetic typography tools that display text in a style indicative of one's current state), or the automatic integration of media or sensed activity data within the text of sharing messages.

5.3.2 In-the-moment vs Reflective Feedback. Participants' sharing behaviors in the present study suggest that an expressive biosignal system that only accommodates in-the-moment sharing of physiological data may be inherently limited. Most participants were simply not able or not inclined to respond to all sharing notifications, either for logistical reasons (e.g., not having access to one's phone or the ability to use it in moments when noteworthy changes to heart rate have occurred) or motivational ones (e.g., habituating to the repeated prompts to share or feeling disinclined to continuously make decisions to share). One solution, as discussed in the previous section, is to enhance the system's awareness of a user's context in order to achieve a finer-grained accuracy for delivering sharing prompts. Another solution is to equip the user with the ability to receive post-hoc, retrospective access to their data from a previous time period (e.g., the last 24-48 hours) to allow them to reflect on their physiological responses and their meaning before making decisions to share. Such reflective feedback features would also give users the opportunity to ponder the longer-term patterns in their own biosignals. This could encourage users to make meaning of their responses, their likely contextual or situational triggers or antecedents, and the most personally beneficial or appropriate ways of sharing their data. In future iterations of our own system, we will expand the functionality to accommodate both in-the-moment sharing, which may be appropriate when users desire to share immediately, as well as reflective, retroactive sharing, which may be more effective for activities that preclude phone access or require more time to contemplate.

5.3.3 Increasing Appeal. Participants offered a number of observations and recommendations for ways to increase the usability and expand the functionality of the system in order to make it a more pleasurable experience. For example, several participants noted the constraint of being able to share only a single numeric indicator of their heart rate, and expressed a desire for a wider array of options for both the data available to share (e.g., trends in their heart rate, blood pressure, steps taken) and the means of depicting or presenting the data (e.g., the use of graphical or image-based representations of heart rate).

> *People wouldn't be interested in seeing just a number...it would have been much better if it was shared as a gif to people.... So the time wouldn't matter...since they don't have to do an extra work of opening a link...people would be more willing to see it.* - P28

In addition to gif replays of heart rate, participants suggestions for visualizations included heart beat graphs (as opposed to heart rate, which has slower and less engaging visual changes), and heart images to make the expression of heart rate more vivid. In our future work, we will explore different visual designs to present heart rate in a more engaging and expressive manner.

5.3.4 Product Improvements. In sum, heart rate sharing technologies should consider implementing new designs or features to support sharers' intentions and desires to share, as well as receivers' understanding of the shared heart rate. In particular, existing heart rate sharing technologies do not support contexts for sharing that could facilitate users' self-expression and interactions with their contacts. The Apple Watch, for instance, allows users to share their heartbeat with their contacts through graphic and haptic feedback, yet does not provide a clear incentive for users to do so. While the feedback provides a visually appealing format for sharing heart rate, the application would benefit by signaling to users the right moment to share. Considering Affective Computing solutions for detecting emotional states, or working in combination with other existing sensed data,

such as location or activity, to provide context, could help users identify these interesting moments for both in-the-moment sharing and post-hoc reflection. For instance, one participant suggested adding an accelerometer to the application in order to identify these moments:

> *Maybe it could have an accelerometer or something, so it could actually detect what I'm doing.... If my heart rate shoots up it should understand why it shot up... I believe the ultimate goal...is to send out of the ordinary readings, I would want it to send me something unexpected.* - P60

Customizable settings could also reduce the need to attend to application notications by allowing for personalized automated share messages or limiting acceptable times for sharing. Additionally, given the intimacy and personal nature of heart rate sharing, current and future products should incorporate privacy settings that give users control over when, with whom, and how they want to share. Exploring these potential design solutions is a focus of the next phase of our research.

6 LIMITATIONS

We sought to investigate heart rate sharing in users' everyday contexts, employing a combination of ESM and semi-structured interviews. In order to encourage more natural sharing behaviors, we had participants use their own phones and messaging applications to communicate with their contacts during the study. This allowed for a higher level of ecological validity in studying how participants would use the application in the wild; however, the diversity of lifestyles as well as the lack of uniformity in the models of phones used by participants inevitably resulted in irregularities and difficulties in data collection. For instance, participants would not always receive or see ten notifications each day and different participants could receive different numbers of notifications based on their activities, availability, and the accessibility of their phones, subsequently affecting the number of sharing opportunities. Similarly, participants answered varying numbers of ESM questionnaires. Both cases usually resulted from the fact that participants could not always attend to to their phone or even have it on their person.

Irregularities in notification prompts were exacerbated by the two-device system setup, where heart rate was streamed from the Mio Alpha 2 watch to users' mobile phones. All participants experienced Bluetooth connectivity issues at some point during the study, interrupting the stream of their heart rate to the phone. The frequency of these connection issues also varied across different phones, as participants had a range of devices, including those from the Samsung Galaxy series, OnePlus, Huawei, HTC, and Motorola. Participants also occasionally forgot to wear their watches or to charge them overnight, despite reminders on their phones and daily check-ins from the experimenters; thus, they may have experienced a few hours of lost sharing opportunities. However, despite these irregularities, we were able to glean an ample amount of data from all participants to inform our analysis around their sharing behaviors. Future work may also be able to mitigate some of these issues with further advances in heart rate monitoring technology in smartwatches, which would eliminate the need for two devices by delivering prompts on the watch itself rather than via a connected phone application.

The study was also limited in its heart rate sharing capabilities. Specifically, the setup of the study only allowed for one-way heart rate sharing, as participants' contacts were not equipped with the study application or heart rate monitors. One participant actively wondered whether any of her contacts would send their heart rate back to her whenever she shared, but was unsure if they had a heart rate monitor that could support this. For the purposes of this study, we focused on heart rate sharing at the individual level, focusing on individuals' decisions to share their heart rate and how they felt afterwards. We were also interested in understanding how individuals would explain their shared heart rate and decisions to share with their contacts, who would have no prior knowledge of the study, and gauge the initial reactions they would receive, given that heart rate sharing is a novel type of interaction. However, social interactions and feelings about heart rate could change when both parties have the ability to share their heart rate with each other. In our future work, we plan on investigating equal heart rate sharing at the dyadic and group levels to explore these possibilities.

7 CONCLUSION

By exploring heart rate sharing *in situ*, the present study revealed that heart rate sharing could support interactions and even open up new lines or forms of interaction. At the same time, the results revealed particular issues, such as ambiguity around the meaning of the heart rate value itself and its potential for expressing personal intimacy or vulnerability, that affected heart rate sharing behaviors and outcomes. The findings that emerged provide an initial glimpse of the promise and potential of heart rate sharing applications for supporting social interactions and, at the same time, identify key considerations for the design and development of systems that support the sharing of heart rate as a powerful social cue for communication and personal expression.

REFERENCES

[1] 2016. Muse. http://www.choosemuse.com/. (2016). Accessed: 2017-07-13.

[2] 2017. Mio Alpha 2. https://www.mioglobal.com/en-us/Mio-ALPHA-2-Heart-Rate-Sport-Watch/Product.aspx. (2017). Accessed: 2017-05-12.

[3] 2017. Monitor stress, seizures, activity, sleep. https://www.empatica.com/product-embrace. (2017). Accessed: 2017-07-13.

[4] Keith Anderson, Elisabeth André, Tobias Baur, Sara Bernardini, Mathieu Chollet, Evi Chryssafidou, Ionut Damian, Cathy Ennis, Arjan Egges, Patrick Gebhard, et al. 2013. The TARDIS framework: intelligent virtual agents for social coaching in job interviews. In *Advances in computer entertainment*. Springer, 476–491.

[5] Chris Berka, Daniel J Levendowski, Milenko M Cvetinovic, Miroslav M Petrovic, Gene Davis, Michelle N Lumicao, Vladimir T Zivkovic, Miodrag V Popovic, and Richard Olmstead. 2004. Real-time analysis of EEG indexes of alertness, cognition, and memory acquired with a wireless EEG headset. *International Journal of Human-Computer Interaction* 17, 2 (2004), 151–170.

[6] Prashant Bordia. 1997. Face-to-face versus computer-mediated communication: A synthesis of the experimental literature. *The Journal of Business Communication (1973)* 34, 1 (1997), 99–118.

[7] Sunny Consolvo, Ian E Smith, Tara Matthews, Anthony LaMarca, Jason Tabert, and Pauline Powledge. 2005. Location disclosure to social relations: why, when, & what people want to share. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 81–90.

[8] Sunny Consolvo and Miriam Walker. 2003. Using the experience sampling method to evaluate ubicomp applications. *IEEE Pervasive Computing* 2, 2 (2003), 24–31.

[9] Jean Costa, Alexander T Adams, Malte F Jung, François Guimbetiere, and Tanzeem Choudhury. 2016. EmotionCheck: leveraging bodily signals and false feedback to regulate our emotions. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 758–769.

[10] Franco Curmi, Maria Angela Ferrario, Jen Southern, and Jon Whittle. 2013. HeartLink: open broadcast of live biometric data to social networks. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1749–1758.

[11] Daantje Derks, Agneta H Fischer, and Arjan ER Bos. 2008. The role of emotion in computer-mediated communication: A review. *Computers in Human Behavior* 24, 3 (2008), 766–785.

[12] Rana El Kaliouby, Rosalind Picard, and Simon Baron-Cohen. 2006. Affective computing and autism. *Annals of the New York Academy of Sciences* 1093, 1 (2006), 228–248.

[13] Clark Elliott, Jeff Rickel, and James Lester. 1999. Lifelike pedagogical agents and affective computing: An exploratory synthesis. In *Artificial intelligence today*. Springer, 195–211.

[14] Daniel A Epstein, Bradley H Jacobson, Elizabeth Bales, David W McDonald, and Sean A Munson. 2015. From nobody cares to way to go!: A Design Framework for Social Sharing in Personal Informatics. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*. ACM, 1622–1636.

[15] Muhammad Fahim, Iram Fatima, Sungyoung Lee, and Young-Koo Lee. 2012. Daily life activity tracking application for smart homes using android smartphone. In *Advanced Communication Technology (ICACT), 2012 14th International Conference on*. IEEE, 241–245.

[16] Denzil Ferreira, Vassilis Kostakos, and Anind K Dey. 2015. AWARE: mobile context instrumentation framework. *Frontiers in ICT* 2 (2015), 6.

[17] Jérémy Frey. 2016. Remote Heart Rate Sensing and Projection to Renew Traditional Board Games and Foster Social Interactions. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, 1865–1871.

[18] Laurent George and Anatole Lécuyer. 2010. An overview of research on" passive" brain-computer interfaces for implicit human-computer interaction. In *International Conference on Applied Bionics and Biomechanics ICABB 2010-Workshop W1" Brain-Computer Interfacing and Virtual Reality"*.

[19] Avik Ghose, Priyanka Sinha, Chirabrata Bhaumik, Aniruddha Sinha, Amit Agrawal, and Anirban Dutta Choudhury. 2013. UbiHeld: ubiquitous healthcare monitoring system for elderly and chronic patients. In *Proceedings of the 2013 ACM Conference on Pervasive and*

Ubiquitous Computing Adjunct Publication. ACM, 1255–1264.
[20] Erin Griffiths, T Scott Saponas, and AJ Brush. 2014. Health chair: implicitly sensing heart and respiratory rate. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 661–671.
[21] Mariam Hassib, Daniel Buschek, Pawel W. Wozniak, and Florian Alt. 2017. HeartChat: Heart Rate Augmented Mobile Chat to Support Empathy and Awareness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 2239–2251.
[22] Mariam Hassib, Stefan Schneegass, Philipp Eiglsperger, Niels Henze, Albrecht Schmidt, and Florian Alt. 2017. EngageMeter: A System for Implicit Audience Engagement Sensing Using Electroencephalography. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 5114–5119.
[23] Jennifer A Healey and Rosalind W Picard. 2005. Detecting stress during real-world driving tasks using physiological sensors. *IEEE Transactions on intelligent transportation systems* 6, 2 (2005), 156–166.
[24] Javier Hernandez, Ivan Riobo, Agata Rozga, Gregory D Abowd, and Rosalind W Picard. 2014. Using electrodermal activity to recognize ease of engagement in children during social interactions. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 307–317.
[25] Karen Hovsepian, Mustafa al'Absi, Emre Ertin, Thomas Kamarck, Motohiro Nakajima, and Santosh Kumar. 2015. cStress: towards a gold standard for continuous stress assessment in the mobile environment. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 493–504.
[26] Noura Howell, Laura Devendorf, Rundong Kevin Tian, Tomás Vega Galvez, Nan-Wei Gong, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. Biosignals as Social Cues: Ambiguity and Emotional Interpretation in Social Displays of Skin Conductance. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, 865–870.
[27] Joris H Janssen, Jeremy N Bailenson, Wijnand A IJsselsteijn, and Joyce HDM Westerink. 2010. Intimate heartbeats: Opportunities for affective communication technology. *IEEE Transactions on Affective Computing* 1, 2 (2010), 72–80.
[28] Dacher Keltner and Jonathan Haidt. 1999. Social functions of emotions at four levels of analysis. *Cognition & Emotion* 13, 5 (1999), 505–521.
[29] Eileen Kennedy-Moore and Jeanne C Watson. 2001. How and when does emotional expression help? *Review of General Psychology* 5, 3 (2001), 187.
[30] Sara Kiesler, Jane Siegel, and Timothy W McGuire. 1984. Social psychological aspects of computer-mediated communication. *American psychologist* 39, 10 (1984), 1123.
[31] Reuben Kirkham, Sebastian Mellor, David Green, Jiun-Shian Lin, Karim Ladha, Cassim Ladha, Daniel Jackson, Patrick Olivier, Peter Wright, and Thomas Ploetz. 2013. The break-time barometer: an exploratory system forworkplace break-time social awareness. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 73–82.
[32] Evdokimos I Konstantinidis, Magda Hitoglou-Antoniadou, Andrej Luneski, Panagiotis D Bamidis, and Maria M Nikolaidou. 2009. Using affective avatars and rich multimedia content for education of children with autism. In *Proceedings of the 2nd International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 58.
[33] Reed Larson and Mihaly Csikszentmihalyi. 1983. The experience sampling method. *New Directions for Methodology of Social & Behavioral Science* (1983).
[34] Robert W Levenson and Anna M Ruef. 1997. Physiological aspects of emotional knowledge and rapport. (1997).
[35] Danielle Lottridge, Nicolas Masson, and Wendy Mackay. 2009. Sharing empty moments: design for remote couples. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2329–2338.
[36] Xuan Lu, Wei Ai, Xuanzhe Liu, Qian Li, Ning Wang, Gang Huang, and Qiaozhu Mei. 2016. Learning from the ubiquitous language: an empirical analysis of emoji usage of smartphone users. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 770–780.
[37] Diana MacLean, Asta Roseway, and Mary Czerwinski. 2013. MoodWings: a wearable biofeedback device for real-time stress intervention. In *Proceedings of the 6th International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 66.
[38] Paolo Massa, Chiara Leonardi, Bruno Lepri, Fabio Pianesi, and Massimo Zancanaro. 2015. If you are happy and you know it, say "I'm here": investigating parents' location-sharing preferences. In *Human-Computer Interaction*. Springer, 315–332.
[39] Nick Merrill and Coye Cheshire. 2016. Habits of the Heart (rate): Social Interpretation of Biosignals in Two Interaction Contexts. In *Proceedings of the 19th International Conference on Supporting Group Work*. ACM, 31–38.
[40] Nick Merrill and Coye Cheshire. 2017. Trust Your Heart: Assessing Cooperation and Trust with Biosignals in Computer-Mediated Interactions. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. ACM, 2–12.
[41] Hannah Jean Miller, Jacob Thebault-Spieker, Shuo Chang, Isaac Johnson, Loren Terveen, and Brent Hecht. 2016. "Blissfully Happy" or "Ready to Fight": Varying Interpretations of Emoji. In *Proceedings of the 10th International Conference on Web and Social Media*.
[42] Hyeryung Christine Min and Tek-Jin Nam. 2014. Biosignal sharing for affective connectedness. In *Proceedings of the 2014 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, 2191–2196.
[43] Florian Mueller, Frank Vetere, Martin R Gibbs, Darren Edge, Stefan Agamanolis, and Jennifer G Sheridan. 2010. Jogging over a distance between Europe and Australia. In *Proceedings of the 23nd annual ACM symposium on User interface software and technology*. ACM,

189–198.
[44] Pablo Pancardo, JA Hernández-Nolasco, Francisco D Acosta, and Miguel A Wister. 2016. Personalizing Physical Effort Estimation in Workplaces Using a Wearable Heart Rate Sensor. In *Ubiquitous Computing and Ambient Intelligence: 10th International Conference, UCAmI 2016, San Bartolomé de Tirajana, Gran Canaria, Spain, November 29–December 2, 2016, Part II 10*. Springer, 111–122.
[45] Helmut Prendinger and Mitsuru Ishizuka. 2005. The empathic companion: A character-based interface that addresses users'affective states. *Applied Artificial Intelligence* 19, 3-4 (2005), 267–285.
[46] John Rooksby, Mattias Rost, Alistair Morrison, and Matthew Chalmers Chalmers. 2014. Personal tracking as lived informatics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1163–1172.
[47] Jonathan Rubin, Hoda Eldardiry, Rui Abreu, Shane Ahern, Honglu Du, Ashish Pattekar, and Daniel G Bobrow. 2015. Towards a mobile and wearable system for predicting panic attacks. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 529–533.
[48] Johnny Saldaña. 2015. *The coding manual for qualitative researchers*. Sage.
[49] Akane Sano and Rosalind W Picard. 2013. Stress recognition using wearable sensors and mobile phones. In *Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on*. IEEE, 671–676.
[50] Holger Schnädelbach, Stefan Rennick Egglestone, Stuart Reeves, Steve Benford, Brendan Walker, and Michael Wright. 2008. Performing thrill: designing telemetry systems and spectator interfaces for amusement rides. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1167–1176.
[51] Petr Slovák, Joris Janssen, and Geraldine Fitzpatrick. 2012. Understanding heart rate sharing: towards unpacking physiosocial space. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 859–868.
[52] Ian Smith, Sunny Consolvo, Anthony Lamarca, Jeffrey Hightower, James Scott, Timothy Sohn, Jeff Hughes, Giovanni Iachello, and Gregory D Abowd. 2005. Social disclosure of place: From location technology to communication practices. In *Proceedings of the 3rd International Conference on Pervasive Computing*. Springer, 134–151.
[53] Jaime Snyder, Mark Matthews, Jacqueline Chien, Pamara F Chang, Emily Sun, Saeed Abdullah, and Geri Gay. 2015. Moodlight: Exploring personal and social implications of ambient display of biosensor data. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*. ACM, 143–153.
[54] Mayu Sumida, Teruhiro Mizumoto, and Keiichi Yasumoto. 2013. Estimating heart rate variation during walking with smartphone. In *Proceedings of the 2013 ACM International Joint conference on Pervasive and Ubiquitous Computing*. ACM, 245–254.
[55] Chiew Seng Sean Tan, Johannes Schöning, Kris Luyten, and Karin Coninx. 2014. Investigating the effects of using biofeedback as visual stress indicator during video-mediated collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 71–80.
[56] Karen P Tang, Jialiu Lin, Jason I Hong, Daniel P Siewiorek, and Norman Sadeh. 2010. Rethinking location sharing: exploring the implications of social-driven vs. purpose-driven location sharing. In *Proceedings of the 12th ACM International Conference on Ubiquitous Computing*. ACM, 85–94.
[57] Gerben A Van Kleef. 2009. How emotions regulate social life: The emotions as social information (EASI) model. *Current directions in psychological science* 18, 3 (2009), 184–188.
[58] Jo Vermeulen, Lindsay MacDonald, Johannes Schöning, Russell Beale, and Sheelagh Carpendale. 2016. Heartefacts: Augmenting mobile video sharing using wrist-worn heart rate sensors. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, 712–723.
[59] Dhaval Vyas, Marek van de Watering, Anton Eliëns, and Gerrit van der Veer. 2007. Engineering social awareness in work environments. *Universal Access in Human-Computer Interaction. Ambient Interaction* (2007), 254–263.
[60] Wouter Walmink, Danielle Wilde, and Florian'Floyd' Mueller. 2014. Displaying heart rate data on a bicycle helmet to support social exertion experiences. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*. ACM, 97–104.
[61] Julia Werner, Reto Wettach, and Eva Hornecker. 2008. United-pulse: feeling your partner's pulse. In *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services*. ACM, 535–538.
[62] Jason Wiese, Patrick Gage Kelley, Lorrie Faith Cranor, Laura Dabbish, Jason I Hong, and John Zimmerman. 2011. Are you close with me? are you nearby?: investigating social groups, closeness, and willingness to share. In *Proceedings of the 13th International Conference on Ubiquitous Computing*. ACM, 197–206.
[63] Svetlana Yarosh, Panos Markopoulos, and Gregory D Abowd. 2014. Towards a questionnaire for measuring affective benefits and costs of communication technologies. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*. ACM, 84–96.

Received May 2017; accepted July 2017.