HeartChat: Heart Rate Augmented Mobile Messaging to Support Empathy and Awareness

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ABSTRACT

Textual communication via mobile phones suffers from a lack of context and emotional awareness. We present a mobile chat application, HeartChat, which integrates heart rate as a cue to increase awareness and empathy. Through a literature review and a focus group, we identified design dimensions important for heart rate augmented chats. We created three concepts showing heart rate per message, in real-time, or sending it explicitly. We tested our system in a two week in-the-wild study with 14 participants (7 pairs). Interviews and questionnaires showed that HeartChat supports empathy between people, in particular close friends and partners. Sharing heart rate helped them to implicitly understand each other's context (e.g. location, physical activity) and emotional state, and sparked curiosity on special occasions. We discuss opportunities, challenges, and design implications for enriching mobile chats with physiological sensing.

Author Keywords

heart rate, instant messaging, affective computing, physiological sensing

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation

INTRODUCTION

The ubiquity and cultural acceptance of mobile chat applications have rendered them one of the most used communication channels in the past years. However, communicating context and emotions, and achieving intimacy, awareness and understanding through mobile chats is still a challenging problem recognized by the literature [9, 10]. To express emotion, users may currently send emoticons, images and other media, which can be understood differently [20, 37].

In this work, we investigate how chat applications can be augmented by communicating physiological data. We argue that wearable physiological sensors can offer an additional channel to communication: Research has proven the relevance of

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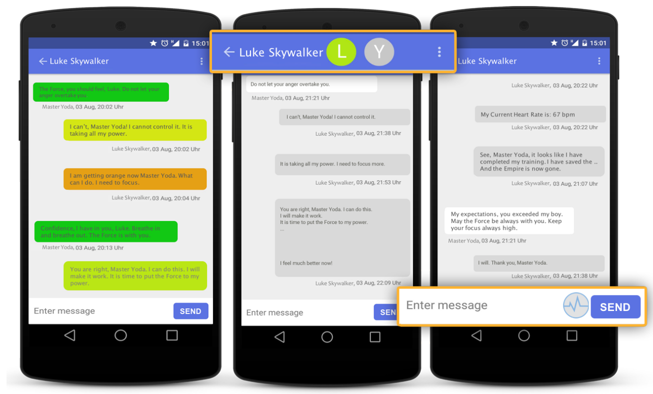

Figure 1. The three implemented view concepts of HeartChat. (A) HeartBubbles: shows color coded messages that reflect the heart rate of the message sender at the time of sending the message. (B) HeartLight: shows the color coded current heart rate of both the sender and receiver when they are both online (in app header, magnified). If one of the users is currently offline, their circle is shown as grey. (C) HeartButton: sends the current heart rate via an extra button (see magnified region).

physiological signals in communicating affect, and increasing empathy and connectedness in social situations [21, 27]. Unobtrusive sensing of physiological signals has now proliferated into mainstream use. In particular, heart rate sensors are now embedded into many wearable devices on the market (e.g. Apple watch[1], Fitbit[2], Moto 360[3]).

We propose *HeartChat*, a mobile chat application which embeds heart rate information into a chat environment. We examine important design dimensions through an extensive review of the literature and market, as well as a user-centered design process with a focus group. We conducted a mixed-methods field study to evaluate the use of heart rate in an ecologically valid environment. We recruited pairs of participants, who were used to chatting with each other, and introduced them to HeartChat, which they then used to chat for two weeks. Interviews, questionnaires and log data show that heart rate sharing in chat promotes empathy, acts as a subtle contextual cue and triggers engaging and playful interactions between interlocutors. Our insights are relevant for researchers and designers working on future mobile chat applications which aim to support intimacy, awareness and connectedness.

[1]Apple Watch: `www.apple.com/watch/`
[2]Fitbit Charge: `www.fitbit.com/chargehr`
[3]Moto360: `www.motorola.com/us/products/moto-360`

Our research contributes: (1) The design and implementation of HeartChat, a heart-rate augmented mobile chat application. (2) An in-depth exploration of heart-rate augmented mobile chatting in a two-week in-the-wild study. (3) A discussion of the implications of heart rate as a physiological dimension for mobile chats with design recommendations for mobile messengers augmented with physiological data.

RELATED WORK

We divide prior work that influences our research into three groups: affective instant messaging applications, mobile applications using physiological data, and heart rate sharing.

Contextual and Affective Instant Messaging

Since the rise of instant messaging and chat applications, both mobile and desktop-based, researchers have been trying to increase these channels' context awareness and emotional expressiveness. They have employed a variety of techniques, including face recognition, physiological sensing and natural language processing, in order to augment and adapt chat output to reflect emotional state and context.

One way of embedding affective and contextual information in chats is animated text ("*kinematic typography*"). Wang et al. map physiological sensors to text animation to convey emotion in conversation [38]. Lee et al. designed several text effects to convey emotions through text analysis [17]. More recently, Buschek et al. implemented *TapScript*, a mobile chat application which uses custom fonts and phone sensors to add font effects to communicate context [3].

Researchers investigated ways to visualize the atmosphere of chats based on textual analysis, patterns and emoticons. Vigas and Donath presented *Chat Circles*, a desktop chat application which uses abstract visuals to present identity and activity in synchronous communication [34]. *Bubba Talk* maps text styles and patterns (e.g., capitals, exclamation marks) to different visualizations that show the chat's general mood [30]. *CrystalChat* visualizes the history of conversations based on several patterns of conversation including emotions in chat as represented by emoticons [31]. Pong et al. presented *GamIM* [22], an instant messaging application that shows a chat's general atmosphere synchronously in real-time based on text analysis. Tsetserukou et al. created *I_FeelIMI!* [32], which uses text analysis to extract emotions and communicate feedback through wearable garment (e.g., for virtual hugs). Kaliouby and Robinson [8], Fabri et al. [10], as well as Angesleva et al. [1] used facial recognition to communicate chat partners' emotional states via images and avatars.

More recently, researchers utilized wearables with physiological sensors for sharing affect and context in messaging. Lee et al. developed *EmpaTalk* [18], a video chat application which mutually shows heart rate and skin wetness collected through blood volume pulse (BVP) together with galvanic skin response (GSR). *Conductive Chat* [7] uses GSR sensors to communicate arousal in chat by animating the text. Kuber and Wright used electroencephalography (EEG) signals from the brain and facial expressions to detect emotional cues in instant messaging [16].

Heart Rate Sharing

Heart rate (HR) sensors recently moved from the medical domain to mainstream, e.g., in fitness trackers (e.g., Fitbit, Jawbone) and smart watches (e.g., Apple Watch, Moto 360). Consequently, researchers investigated HR sharing in sports / social fitness and for increasing intimacy and connectedness.

Curmi et al. explored sharing HR in real-time with the public during sport events [5]. They further investigated sharing biometric data in social networks [6]. Walmink et al. found that sharing HR on a bicycle helmet at cycling events supported engagement [35]. Khot et al. visualized and shared HR at sport events through an interactive water fountain [14].

Based on the results of such prior work, heart rate is regarded as an intimate and emotional cue. However, people hold reservations towards direct uncontrolled sharing [5, 13, 27]. Hence, researchers examined HR sharing via private channels to increase connectedness: Slovak et al. [27] deployed a technology probe in family homes for two weeks, and qualitatively assessed people's impressions regarding HR sharing. They concluded that it can be used as (1) information and (2) connection. Further investigating HR sharing in long-distance relationships, Werner et al. developed *United-Pulse* [39], a ring that makes couples feel each other's heart beat remotely to increase feelings of closeness. The success of these projects motivate our use of HR. In contrast to prior work, we examine HR sharing directly embedded in an existing text-based mobile communication channel, namely a chat application. Past work developed custom technology that required creating new habits. Our research is different as we investigate if physiological data sharing can be embedded in existing routines.

Physiological Data Augmented Mobile Applications

Researchers studied integrating physiological sensors with mobile apps: *AffectCam* [23] and *Affectiview* [26] use GSR sensors to augment pictures and videos with affective responses. Miyauchi et al. developed *Listen to Your Heart*, a novel way to interact with public displays using HR information synchronized on a phone. Vermeulen et al. built *Heartefacts* [33], a mobile system which uses HR data from wrist-worn sensors to create short video highlights on the phone.

In summary, past work investigated augmenting instant messaging with additional information for better affect and context awareness. Heart rate sharing has been proven to increase awareness and connectedness in different situations from sports to home contexts. However, prior work has not designed concepts for integrating heart rate in a mobile chat context. Whereas some lab studies of augmenting instant messaging in desktop and mobile environments exist, to our knowledge no studies investigated longer-term usage of heart rate augmented chats in the wild. We address that gap by designing and deploying an augemnted chat application.

DESIGN

The development of our concept is based on two steps. First, we chart the design dimensions for physiological messaging based on a review of related literature and commercial mobile chat applications augmented with physiological or affective information. Secondly, we conducted a focus group to identify core dimensions for the implementation.

Design Dimensions of Physiological Chat

Our design dimensions are based on an extensive review of related work. We searched Google scholar and the ACM Digital Library using the following terms: *physiological, biometric, instant messaging*, *heart rate sharing chat*. This search yielded 50 papers that contained relevant keywords. An abstract review was conducted to identify 22 papers relevant to our work. We also reviewed the description of 30 applications on the Apple Store and in Google Play Store which contained the keywords for: *Heart Rate* and *sharing*. Relevant applications were installd and studied in detail. We identified the following dimensions:

Data Representation: Research artefacts and market apps explored different ways to represent physiological and facial information in chats. The representations can either be *raw* or *interpreted*. Raw representations show the physiological data as a numeric value or raw signal [35]. Interpreted representations include translating the physiological information into abstract visualizations [27], colors the messages or chat environment [22] or animates text [8]. Raw numerical representation can be clear in case of heart rate. However, they can also be overwhelming in case of other physiological data such as GSR and EEG. On the other hand, physiological data, whether heart rate, GSR, EEG or other signals, are highly person dependent, and *interpreted* representations balance that out to allow for better comparisons and understanding[28].

Commercially available wearable sensors (e.g., Apple Watch) or mobile applications (Android Heart Rate) currently do not directly embed physiological/sensed information in chat, but allowing the users to share the information to other applications in the chat. Typically, the information gets sent as a chat message in a raw format. The Apple watch however, allows sharing haptic heart rate information to other users owning an Apple watch and not through a chat application.

Sharing Triggers: The collected physiological information can be triggered for sharing in a chat in two ways: either through an *explicit trigger by the user* or through an *implicit trigger by the system*. Explicit user triggering gives the user the complete control over what and when to share, since users can press a button voluntarily whenever they like. Implicit system triggering embeds the information in the chat message directly without interference from the user. Implicit triggering can also be message-based (for example, each time a message is sent) or real-time (for example, instantly updated next to the name of the user). All current market mobile applications allow users to explicitly choose a sharing platform to share the heart rate, whereas most research systems use implicit, system-triggered sharing [5, 6, 27].

Persistence: The augmented physiological or affective information can be *ephemeral*, where it is presented in real-time and disappears right away, or *persistent* and historical over a period of time. Researchers looked into various ways of visualizing historical representations in post-hoc after the interaction is over [30, 31]. Other applications only showed the physiological information (for example, heart rate) ephemerally during the chat conversation [19].

Granularity: The visualized information can be *person-based* or *conversation-based*. As mobile chatting and instant messaging in general is a social activity, visualizing the physiological information as a group where each person in the chat contributes to the overall *atmosphere* has been researched [22]. Other applications mentioned in prior sections mostly employ a person-based visualization of affect or physiological information in the chat by adding facets to each chat message.

Focus Group

As the next step, we conducted a focus group to gather extended user feedback on designing for heart rate sharing.

The focus group consisted of two parts. In the first part we uncovered ways in which users currently share their context and emotions during mobile chatting and the situations in which they feel that the current ways of self-expression are not sufficient. The second part was dedicated to introducing the idea of a heart-rate augmented mobile chat application, its benefits and drawbacks, as well as a hands-on design session, in which participants came up with ideas for integrating heart rate into a regular chat GUI. The resulting designs and discussions were used to inform our design of HeartChat.

Six participants between 23 and 35 years old ($M = 25$, $SD = 5.4$, 2 female) took part in our focus group. Participants were mainly bachelor, master, or doctoral students of several faculties including sociology, physics, psychology, and computer science. All used mobile chat applications daily. The session lasted 90 minutes and was video recorded. Two researchers were present: a facilitator and an observer who took notes.

Participants signed consent forms. We then explained the topic of the focus group. First we discussed their current mobile chatting preferences and reasons for choosing particular apps. The discussion then moved on to emotional cues in chats (e.g., emoticons), and when and how often they are used. Afterwards, we discussed opportunities and challenges of heart-rate sensing as an implicit emotional cue for increasing awareness, engagement and empathy in chats. The rest of the session was "hands-on": Participants created several mock-ups of heart-rate augmented mobile chat interfaces. Finally, we conducted a group discussion, including voting on all mock-ups and ideas.

To identify themes, we used the video recording and audio transcription as well as the observer's collected comments.

Focus Group Findings

Applications and Usage Patterns

All of our participants use mobile chat apps daily. Four participants mainly use *WhatsApp* because of its wide user base. Two participants (P1, P2) mainly use Telegram and Threema because of higher security. Additionally, P1 and P2 also like the use of stickers as provided by the Telegram application.

Emotional Expression in Chat

We asked participants how they express their emotions in chatting using emoticons and in which situations. P1 stated that she uses emoticons in every message she sends, whereas P5 mentioned that he rarely uses emoticons and only sends them to depict irony and sarcasm. P3 mentioned that his use of emoticons in chat entirely depends on who he is talking to and the extent of their relationship.

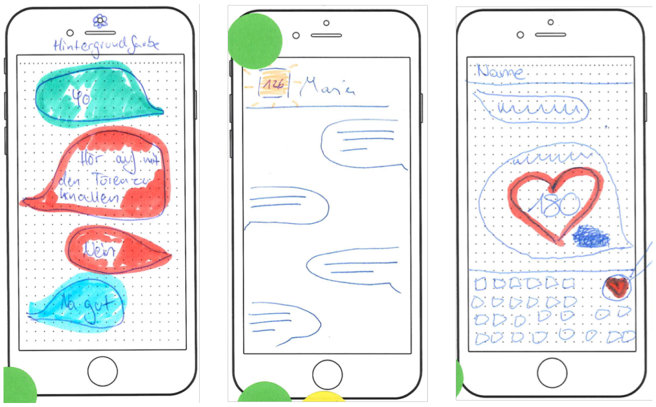

Figure 2. The three top-voted concept designs from the user design session: (A) The first design uses colored chat bubbles, where color varies depending on the heart rate of the message sender at the time of message sensing. (B) In the second design, a colored, continuously blinking shape in the chat header is shown. The color refers to the heart rate of the chat partner. (C) In the third design, a button is added to the keyboard for explicitly sending the current heart rate while chatting. The heart rate is shown in a separate message.

Several participants stated that in case of *anger and arguments* they find it harder to express emotions textually. P3 stated that he uses audio in situations where text will not be enough to show emotions since. Additionally he said that expressing anger over chat is hard due to the pauses given by the chat environment, it is then harder to understand the context through which the other person is in. P1 and P2 stated that they refrain from using emoticons to illustrate a more appropriate conversation mood. Another situation proposed by participants where they need a clearer way of emotional expression was *dating and flirtation.* P6 mentioned *" In case of flirting, I use ":)" instead of actual emoticons because they seem more serious."*

Privacy Concerns and Skepticism

Several participants were skeptic of visualizing heart rate in chats and raised privacy concerns.

Privacy and positive emotional valence: P2 stated that emotions are private and that she would only allow close people to see her feelings, and only positive ones. She said that if her emotional state is negative she will not be talking to people, so she will not be activating this feature in her chat applications. These findings confirm outcomes from prior literature[32, 37].

Trust and control: P4 stated that he will never trust a sensor to get his emotions right. Both P4 and P6 stated that they would only use such a feature if he can approve the emotion predicted before it is being sent in a chat message.

Playfulness and checking: P1 found the idea playful and engaging. She said she would like to play around with the data first – trying to tell a joke, or be ironic – to check if the system correctly reflects her state.

Style and context: P3 mentioned that acceptance depends on how emotions are predicted and visualized. As an example, he stated that a heart rate sensor could also show elevated values while climbing stairs. At that point the message receiver will not know the context and might misunderstand the data.

Perceived Opportunities and Drawbacks

Participants discussed the opportunities and advantages arising from adding heart rate to chat applications. They stated that it is a very easy way for emotional expression (P1), and independent of language (P3). P2 mentioned that this feature definitely increases the honesty of the communication medium. P4 said that it will be playful and hence used by some as a game. When discussing disadvantages, P2 stated that it might be an overload of information in the message environment. Three participants (P4, P5, P6) raised concerns that the data will be wrongly interpreted due to lack of context.

Final Design Concepts

After the first part, participants were given sheets of paper with smart phone stencils to freely sketch their ideas for integrating and visualizing heart rate in chats. We encouraged them to individually come up with different designs which were then discussed and enhanced as a group.

Finally, each participant was given three votes to promote three of the proposed designs. Figure 2 shows the top designs, with 3 to 4 votes each. Design A colors chat bubbles according to the heart rate at the time of sending the message. Design B displays the chat partner's current heart rate as a colored circle next to their name at the top of the screen. Design C offers a button to explicitly send the current heart rate as a message. We utilized the three design concepts for our implementation.

HEARTCHAT

We combined the focus group findings and our literature and market app review with the introduced design dimensions in an iterative design process. As a result, we created HeartChat, a mobile chat app for Android that integrates heart-rate information. Its architecture utilizes the Google Cloud Messaging service[4] and a MySQL database. The database stores messages' timestamps, the text (encrypted), the heart rate, and the current visualisation. The app connects to heart rate sensors via Bluetooth Low Energy (BLE).

HeartChat Views

Following the most voted design concepts (Figure 2), we created three heart rate visualisations (Figure 1):

- *HeartLight:* Presents the heart rate of each chat user as a circle with their initial(s). The circle continuously changes color at 1 Hz while the sensor is connected. The circle is grey for users who are not currently online with HeartChat open. This concept utilizes the dimensions of *real-time ephemeral* and *implicit sending*.
- *HeartBubbles:* Presents the heart rate upon sending a message encoded in the color of the message's bubble, on a scale from green to red. Older message stay colored. This concept thus realises the dimensions of *persistence, history* and *implicit sending*.
- *HeartButton:* Shows a button beside the text field to send a message with the user's current heart rate as a number. No other heart rate augmentation is seen in the chat. This concept realises *raw representation* and *explicit sending*.

[4] https://developers.google.com/cloud-messaging/

Heart Rate Color Coding

To ensure a homogeneous and comparable color representation, we used a color coding that ranges between the baselines of minimum (resting) and maximum heart rate per person. The resting heart rate is calculated by taking the measured heart rate value after around two minutes of resting. The maximum heart rate per person is calculated as $208 - (0.7 * Age)$ [29]. Heart rate values are mapped from green to red in the HSV color spectrum similar to several heart rate market applications and the work of Curmi et Al.[6]. We used a cutoff at 85% of the maximum heart rate which was determined through prestudies. Any heart rate values above the maximum are rarely reached and are represented with the same shade of red.

Text Encryption

To ensure private data exchange between users of HeartChat, we employed the BlowFish encryption algorithm [25]. Each pair of users agreed on a password which they entered on their phones through the application settings. The encrypted messages are then sent and stored via our server. Decryption again happens locally on users' devices.

System Limitations

While HeartChat is a fully functional mobile chat app, it is prone to certain limitations. It does not yet support picture and media sharing. Furthermore, it is currently not possible to chat with people other than participants. This was a deliberate decision to make sure that only recruited and consenting participants are observed during the study.

EVALUATION

We conducted a field study to evaluate HeartChat for a duration of two weeks. In particular, we assessed the experience with the different visualization concepts, the general experience with embedding heart rate information in the chat, and how heart rate was used in an in-the-wild context between chat partners. To the best of our knowledge, no in-the-wild studies exist to evaluate chatting enhanced with physiological data.

Study Design

Independent Variable: Visualization

We compared the three heart rate visualizations with a between subjects design in the first week: Each pair of participants was required to use a particular visualization for the first week.

To gather additional insights into the different views, participants were then allowed to freely try out all three visualizations during the second week of the study.

Data Collection: Interviews, Questionnaires, Logging

We collected information via interviews before and after the study, data logging, and questionnaires on participants' usual chat apps and our app. All interviews were audio recorded.

To evaluate the different aspects of embedding biometric information into a regular chat environment, we employed the Affective Benefits and Costs of Communication Technology (ABCCT) questionnaire [40]. The questionnaire was designed to evaluate the difference between communication technologies with respect to four *benefits*: Emotion Expression, Engagement and Playfulness, Presence in Absence, Opportunity for Social Support, and three *costs*:Unmet Expectations, Unwanted Obligations, Threat to Privacy. The questionnaire was successfully used in comparing new artefacts or new features of communication systems to existing ones [40, 41].

To evaluate the different concept visualizations, we asked participants to express their agreement on a 7-point Likert scale (1=totally disagree, 7=totally agree) about the visualization they were using during the first week, to the statements: "The visualization I was using this week": (1) was clear and easy to interpret, (2) was enjoyable and fun to use, (3) made me feel close and connected to my chat partner, (4) made me understand the state of my chat partner. After the study, participants answered the same questions about all three visualizations.

We logged heart rate, encrypted message, timestamps, and the selected mode of visualization for each message.

Participants

We recruited 14 participants (7 pairs), between 24 and 37 years (M=28 years , SD=3.1, 9 female) to evaluate HeartChat via social media posts and mailing lists. We asked responders to bring along a friend, partner, or family member with whom they chat regularly. Participants were remunerated with a 30 Euro voucher for an online store. Of our 14 participants, four pairs were partners, three pairs were friends. Four participants were master degree students of CS, two were automotive engineers, two were CS researchers, one was a product manager, one a research assistant in electronics, two were researchers in pharmacy, one a graphic designer, and one a UX designer.

Table 1 summarizes the participants' relationship to each other, their locations and their most used chat applications. Only two groups (G6, G7) live in the same household. Two groups (G1, G3) live in the same city, but in different households. Three groups live in different cities/countries. All our participants chat with each other daily multiple times using mobile messaging applications. They all use Whatsapp and Facebook Messenger as their main chat applications.

Four participants owned wearable devices. Three used a heart rate sensor before. One used it for research purposes and the other for fitness tracking. One participant had a regular wristband for step counting and activity recognition.

Procedure

Pre-Study

We first conducted a face-to-face meeting or a video conference call. Participants were first explained the purpose of the study and the application. We explained how they would be compensated. We informed participants that they should use the application as they use a regular chat application. We informed participants that if they chose to abort the study at any time they are free to do so and this will not alter their compensation. They then signed informed consent forms and were given a Google Play link to download the application.

We provided a Polar H7 heart sensing chest strap[5] to each participant and instructed them on how to wear it correctly. It uses two soft electrodes embedded in a chest strap.

[5]Polar Website: http://www.polar.com

Group	Age	Gender	Relationship	Applications	Location	# Msgs.	Active Usage Days	View(W1)	% View(Total)
1	26 28	F F	Friends	Whatsapp	Different households	267	11	HeartBubbles	HB =57% , HL=10% , HT=33%
2	26 28	F F	Friends	Whatsapp, Threema	Different countries	1228	13	HeartLight	HB =38% , HL=56% , HT=6%
3	29 29	M M	Friends	Whatsapp, FB Messenger	Different households	858	14	HeartBubbles	HB =85% , HL=14% , HT=1%
4	29 37	F F	Couple	Whatsapp	Different Cities	375	11	HeartLight	HB =39% , HL=59% , HT=1.6%
5	29 29	M M	Engaged	Whatsapp, Hangouts	Different countries	411	9	HeartButton	HB =8.75% , HL=25% , HT=66%
6	27 27	M F	Married	FB Messenger	Same household	226	8	HeartButton	HB =23% , HL=5.3% , HT=71%
7	29 26	M F	Married	FB Messenger	Same household	699	12	HeartBubbles	HB =87% , HL=1% , HT=12%

Table 1. Participant groups, their demographics and relationship to each other, the most used chat applications and their location with respect to one another, and statistics about HeartChat usage. We present the number of messages exchanged, number of active usage days, view used in week 1 and the total use of each view where HB refers to *HeartBubbles*, HL refers to *HeartLight* and HT refers to *HeartButton*.

We gave participants an overview of HeartChat, the three visualisation concepts and the settings. We instructed them to use the app to measure their resting heart rate by relaxing for two minutes while being seated. We also explained how to change the default encryption settings to add a new mutual password and how the encrypted text looks like in our database.

In the pre-study interview we asked participants about their relationship to one another, the frequency of their contact over mobile chatting, their used apps and patterns of conversation. The interview was audio recorded. Finally, we asked participants to answer the ABCCT questionnaire (referred to as ABCCT(1)) about their currently used mobile chatting app.

During App Usage
We sent participants reminders and asked (once) if they had any feedback or issues using the app. After the first week, we asked participants to fill in the short questionnaire explained in the prior section about the view they had been using. We instructed them that they can now change the view and try out the other views as they wish.

Post-Study
After the study, we interviewed participants to collect their impressions. We provided statistical information about their usage and how their heart rates varied per day. We showed them graphs of their heart rate values visualized per day and discussed interesting aspects (see Figure 4). Participants also completed a questionnaire about the different modes used over the study, and answered the second iteration of the ABCCT questionnaire assessing perceived benefits and costs for HeartChat.

RESULTS
In the following we present the results from the data logs, questionnaires, and interviews. In our discussion of the results we will refer to group number using "G" and participants using "P", so for example Group 1 participant 2 is denoted by (G1P2). For the remainder of the discussion we will refer to the three different concepts of HeartChat as *view*.

Overview
A total of 4064 messages were exchanged between our seven groups (14 participants) during 69 days of active usage of

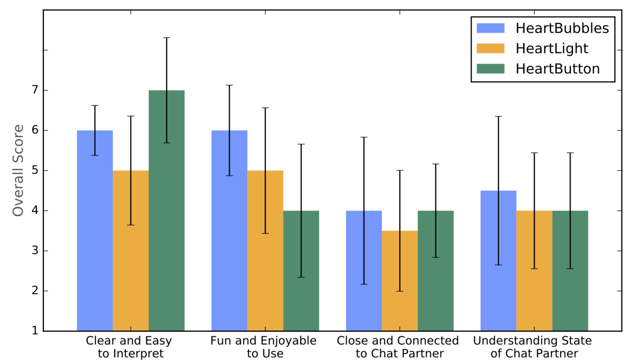

Figure 3. Median and standard deviation scores from the end of study questionnaire about the three visualization concepts: HeartBubbles, HeartLight, HeartButton, regarding ease and clarity, enjoyment and fun, closeness to other, awareness of other's state.

HeartChat. By active usage we refer to days on which participants actually exchanged messages. Six participants used *HeartBubbles* over the first week, four used *HeartLight*, and four used *HeartButton*. Message numbers per group, active days and view usage are depicted in Table 1. During the exit interviews, we presented the following data: 1) Logged numbers of messages, views used, average, minimum and maximum heart rates. 2) Active usage days, showing messages' timings, views, and associated heart rate. Figure 4 shows examples from several days of G2, G4 and G5.

Questionnaires

Comparison of Views (First Use)
Results are based on the questionnaire answered after the first week (i.e. in the "between subjects phase"). We present median results for Likert scale items (1: Totally Disagree, 7: Totally Agree) regarding clarity, enjoyment and fun, connectedness to the interlocutor, and awareness of the interlocutor's state.

Scores show that the *HeartButton* view was clearest and easiest to interpret (*Med*=7, *SD*=0), followed by *HeartBubbles* (*Med*=7, *SD*=0.51) and *HeartLight* (*Med*=4.5, *SD*=2). Participants found *HeartBubbles* to be most enjoyable and fun to use (*Med*=6.5, *SD*=1.7), followed by *HeartLight* (*Med*=4.5, *SD*=0.6) and *HeartButton* (*Med*=3.5, *SD*=2).

Groups who used *HeartBubbles* for the first week stated that it makes them connected to their interlocutors (*Med*=5, *SD*=2) and helps them understand their state (*Med*=5, *SD*=2).

Groups who first used *HeartLight* neither agreed nor disagreed about connectedness (*Med*=4, *SD*=0) and understanding their partner's state (*Med*=4, *SD*=0.5).

Finally, groups first using *HeartButton* slightly disagreed that it made them feel connected to their partners (*Med*=3, *SD*=1.8) and were neutral about whether or not it made them understand their partner's state (*Med*=4, *SD*=1.7). We limited the analysis of the between-subjects first week usage to descriptive statistics since the number of groups is not sufficient for reliable inferential statistics.

Comparison of Views (Overall)

At the end of the study (i.e. after participants had tried out all three views), a second questionnaire assessed the same four aspects for a within-subjects comparison. Figure 3 shows that *HeartButton* scored highest in clarity and ease of interpretation (*Med*=6.5, *SD*=1.3). *HeartBubbles* is the most fun and enjoyable to use (*Med*=6 , *SD*=1.12), allows chat partners to understand each other's states (*Med*=5 , *SD*=1.85) and makes them feel connected (*Med*=5 , *SD*=1.83).

A Friedmann test showed statistically significant differences between views for all four dependent variables: Perceived clarity and ease of interpretation (χ^2=7.682, *p*=0.021), enjoyment and fun (χ^2=8.6, *p*=0.014) , connectedness to interlocutor (χ^2=9.484, *p*=0.009) and awareness of interlocutor's state (χ^2=7.943, *p*=0.019).

Wilcoxon sign-rank tests found no significant differences in perceived clarity between *HeartButton* and *HeartLight* ($Z = -2.275$, *p*=0.023) or between *HeartButton* and *HeartBubbles* (*Z*=$-$0.284, *p*=0.776). Note that due to Bonferroni correction, the significance level is at $p < 0.017$. However, there was a statistically significant reduction in perceived clarity in the *HeartLight* versus *HeartBubbles* view (*Z*=$-$2.699, *p*=0.007). There was a significant increase in awareness of the interlocutor's state when using *HeartBubbles* compared to *HeartLight* (*Z*=$-$2.555, *p*=0.011). We found no significant differences in perceived fun and enjoyment, or in connectedness between any of the pairs of views.

ABBCT Questionnaires

Scores for the ABCCT questionnaires before and after the study were calculated as explained by the authors of the questionnaire [40]. Participants rated 5-point Likert statements – higher scores are better on the four "benefits" scales, whereas lower scores are better on the three "costs" scales.

The ABCCT at the start of the study assessed the benefits and costs of current communication applications (Whatsapp, FB Messenger). It showed that these apps score 3.7 on the *Emotion Expression* scale, 3.4 on the *Engagement and Play*, 3.3 on the *Presence in Absence* scale, and 3.4 on the *Opportunity for social support* benefit scale. On the costs scale, they scored 2 on the *Feeling Obligated*, 2.1 on the *Unmet Expectations* and 1.6 on the *Threat to Privacy* scales.

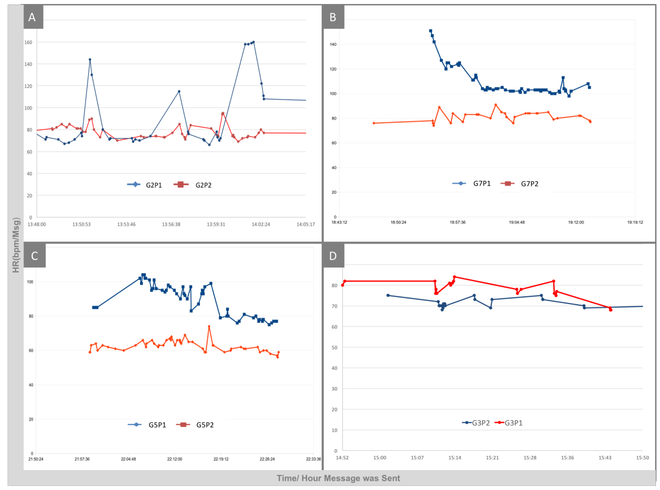

Figure 4. Four examples of log graphs shown to participants during the exit interview. x-axis shows the time/message, y-axis shows the heart rate/message: (A) Conversation from G2 (day 5, *HeartLight*) (B) Conversation from G7 (day 8, *HeartBubbles*), (C) Conversation from G5 (day 6, *HeartButton*) (D) Conversation from G3 (day 12 , *HeartBubbles*)

The ABCCT at the end of the study assessed benefits and costs of our prototype app, HeartChat. It achieved these scores: 3.1 on the *Emotion Expression* scale, 3.3 on the *Engagement and Play*, 2.7 on the *Presence in Absense* scale, and 2.8 on the *Opportunity for social support* benefit scale. On the costs scale, they scored 1.6 on the *Feeling Obligated*, 1.8 in the *Unmet Expectations* and 1.4 in the *Threat to Privacy* scales.

While HeartChat scored lower than market apps on the benefits scale, the above average scores (>2.5) together with feedback from the interviews show that the added heart rate input helped support engagement and play as well as emotion and context awareness (see next section). Also on the benefits scales, 6 users rated HeartChat higher in emotion expression, 9 in engagement and play, 5 in both presence and social support. Additionally, HeartChat scored lower (i.e. better) on the costs scales than market applications.

Interviews

We conducted thematic analysis [2] of the interview data. A total of seven hours of recordings were transcribed for further analysis. Two researchers coded 15% of the material independently. A final coding tree was established through discussion and comparison. The primary author then coded the remaining data. Finally, two researchers looked at these codes and established the four emerging themes discussed below.

Theme 1: Empathy and Awareness

Empathy is an important construct in interpersonal communication. It is defined as the ability to infer another person's state and feelings and respond to it compassionately [10, 11]. In our interviews, empathy and empathetic interactions were a recurrent theme.

Participants mentioned that they were 1) asking their partners how they were feeling or 2) were aware of the other person's feelings or state through the chat and the shared heart rate.

Overall, several people asked their partners what they were doing or why their heart rate was currently high/low (G1P2, G5P1, G2P1, G2P2). For example, G1P2 said: *"Sometimes when her (G2P1's) heart rate was at 120 or something and I asked 'What the heck are you doing?' "*. G2P1 reflected on a day where G2P2 was angry: *"She was really getting angry about this girl and was telling me about what happened."*

G5P1 mentioned that she could track her partner, who has a family history of heart issues, and ask him if he is ok when she feels his heart rate is higher than normal.

G5P2 reported that he was once trying to calm down his partner because she was angry. He used the app to check her heart rate. They exchanged several text messages and used *HeartButton* to track their heart rates until she calmed down.

G2 participants also noted that their heart rates seemed to follow a similar pattern during a couple of conversations represented in their exit interview graphs. G2P1 commented: *"We are really in sync"* whereas G2P2 stated that they are *soulmates*. This also happened with G5 in a conversation where their heart rates were following a similar pattern. G5P1 mentioned that they look *synchronized* whereas G5P2 stated that he thinks this can be expected since they have been talking about a particular topic for 15 minutes (cf. Figure 4, C).

Participants also stated that they could *guess* what their partners were doing (G1P2, G7P2) and where they were (G5, G7). G7P2 mentioned that by the end of the study she could infer from the shade of *yellow* or *red* of the bubbles (in *HeartBubbles* view) and the message timing if her husband is trying to catch the bus his heart rate would be high and once he is in, it got lower so she knew he is already on his way home (cf. Figure 4, B). G1P2 stated that she was aware when her friend was in bed because otherwise her heart rate was much higher.

This intimate awareness and empathy also led to situations in which chat partners expected reciprocity. G3P1 mentioned that he was sometimes expecting the same behavior in heart rate from his friend: *"We were talking about our football team – well my heart rate was definitely going up in the topic but his was always kind of flat!"*.

Theme 2: Everyday Topics

When we showed participants their daily message usage graphs with heart rate, several themes arose regarding everyday topics such as daily habits, food, sports and games.

Several participants (G2, G3) mentioned that talking about food they like made them excited, noting rising heart rates. This promoted playful conversations. G2P2 said that she noted when her friend was excited when they were talking about chocolate and had a laugh about it. G3 had several conversations about their daily lunch menu and new restaurants they would like to try. They were excited to see that both their heart rates were elevated while talking about this topic. G3 often talked about their football team and G3P1 mentioned that he always noted when his heart rate went up because he was annoyed about the team. G1P2 stated that she and her friend often talked about a game (Pokemon GO) and commented on their elevated heart rates when catching a Pokemon.

Several conversations sparked by shared heart rates revolved around changing habits. For example, G1P2 stated that she realized that her daily power walk was not fulfilling its purpose: *"When I go back home this weekend I want to do more sports. I always thought of power walking as a sport but now I see it does not raise my HR that high. I will be getting on my bike."*

Theme 3: Reflection

Participants also reflected on their own heart rates, inspired by their physical or emotional states. A second type of reflection occurred when the app's representation of the person's heart rate triggered them to try to reflect on their state. For example, G2P2 mentioned that she was pretty excited about a sports game on TV during the Olympics, and she noted that her heart rate was high and indicated as red in the *HeartBubbles* view. G2P1 stated that *"There was a lot of the times when I was really just looking at my heart rate and did not send it to G2P2"*. In addition, several participants mentioned that they looked at their heart rate when they were angry to see how high it is, G3P2 stated *"At 2 pm I was very annoyed at someone at work and I can actually see that my heart rate has raised by 5 bpm."*. G1P2 stated that she used the app to observe herself and identify causes of stress. She found this to be particularly useful during a week of exams.

Looking at their own heart rates through the app also triggered reflection among participants. G2P1 stated that she sometimes noticed her heart rate was low and figured out she might be fit due to being rather sportive. G1P2 saw that her heart rate did not go that high during exams but more so afterwards, which surprised her. She stated that *"In general it was a bit of an eyeopener about myself"*. G4P1 also used the app to monitor herself during exercises and send it to her partner: *"Hey look at my heart rate, this is sports at the moment!"*. G3P2 mentioned he discovered to always be rather calm – only thing that strongly influenced his heart rate was strenuous physical activity. He used to look at his heart rate at different situations such as driving or being angry. He stated, reflecting on a conversation on day 12, *" I was pretty angry about something at work but my heart rate only got up to 87 or so. I noted it but it didn't go all the way to red or anything"* (cf. Figure 4, D).

Participants also mentioned that HeartChat somtimes sparked their curiosity (G4P1, G1P2, G5P1). G1P2 stated to have commented on her friend's heart rate every now and then as it was higher than her own and she wanted to know why.

Due to the intimacy of instant messaging in general and the relationships of our participants, they often reflected on privacy of using HeartChat with other people on their contact lists. All participants agreed they would mainly use the implicit views *HeartBubbles, and HeartLight* only with close people. G4P2 would use *HeartBubbles* with family and *HeartButton* with less well-known people. Several other people shared the same opinion. Some mentioned using *HeartButton* as a playful feature with family and friends.

Theme 4: Understanding Heart Rate Augmentation

We asked participants to share their experiences with the different views, and how and when they used each of them. G2P1 stated that although she liked the *HeartBubbles* best, it was still an *overload of colors*. G1P2 stated that she liked the colors as they give a lot more meaning to the numbers. It was intuitive for her to know when her friend was relaxed in the glimpse of an eye from the color. G7 shared the same view. G2P2, G4P1, and G4P2 mentioned that they would like to see more differentiation between small and subtle heart rate changes of few beats in the color coding of the *HeartLight* and *HeartBubble* views. G3 and G4P2 would rather generally see numbers instead of colors. G4P1 used the historical asset of *HeartBubbles* to look back at conversations with her partner.

Several people (G3P2, G2, G1P1) did not see value or meaning in sharing heart rate via *HeartButton*. G3P1 stated that he found it nice to be able to explicitly send a number and that after a while he got a feeling of what the number meant. G1P2 found it *awkward* to use the button without sending an explanation. In contrast, G4P2 liked the button's control over when to send her *internal information* to others. G4 used it only for fun. On the other hand, G5 entirely relied on the button for most of their chats and found the other views to be less useful. G5P2 saw no reason why he should want to know his partner's heart rate from the last day via *HeartBubbles*, and said that the button was the most useful view to him.

G3P1 noted that seeing and sending heart rate in real time loses one advantage of texting, namely the possibility to take one's time to formulate a message. G3P2 found *HeartLight* to be useful for inferring the other's heart rate while reading a sent message. G4P1 stated that she believes the smaller and more subtle heart rate changes to be more interesting because they help infer the emotional state of the person. These can mainly be observed through sending numerical heart rate with the button, whereas color coding shows larger changes. Usually it helped her to infer her partner's physical activity.

DISCUSSION AND DESIGN RECOMMENDATIONS

Self Awareness Through Social Activity

Interviews and logged data show that heart rate augmented chat has not only increased people's awareness of each other's state, but also awareness of themselves. Although self-awareness can be achieved through dedicated fitness tracking or heart rate logging app, the integration with a frequently used and ubiquitous activity of everyday life (i.e. mobile chatting) has proven to be a useful probe for self-awareness which may foster well-being [4]. Participants mentioned they explicitly looked at their own heart rate using *HeartChat*, and experimented with different activities to see how their heart rate changed over time. Users liked that they neither needed a separate medical device (G5P2) nor app (G6P2) to track their heart rate when they are not feeling well, or when doing sports (G4P1) and sharing with their partners.

Design Recommendation: Heart rate, among other physiological signals, provides users with valuable information about their health and fitness. When designing physiological augmented messaging apps this information should be embedded in an easily interpretable and informative way. This adds personal tracking to the benefits of the messaging app and eases the seriousness of occasional medical/fitness tracking that might be associated with dedicated devices and apps.

Heart Rate as an Emotional Cue

Research discussed using heart rate as an emotional cue [27]. In our interviews, participants reported that sharing heart rate helped them to calm down their interlocutors when they were angry (G5), or inform them when their partner was excited about something – this triggered conversations (G2, G1). This was reflected in the emotional awareness results of the ABCCT questionnaire of these groups. On the other hand, G4, G7 and G6 mentioned that a representation of smaller heart rate fluctuations (appr. 5 bpm, only perceivable in *HeartButton*) can facilitate understanding of their partner's emotional state. The color coding sensitivity of the other two views started showing color differences at 10%-15% fluctuations.

In addition, two groups (G2, G5) mentioned to feel like *soulmates* and that they *are in sync* upon looking at their heart rate summary graphs in the exit interview. This also raises the question: Can heart rates of two remote chat partners synchronize? Prior research discussed the phenomenon of involuntary heart rate synchronization between related people when one of them is performing a dangerous task [15] while other research tried to trigger voluntary breath and heart rate synchronization to achieve more intimacy [24]. The question of whether or not heart rate synchronizes remotely and how it can be used to strengthen relationships remains an interesting prospect to discover through a social activity such as mobile chatting.

Design Recommendation: When using heart rate as an emotional cue, representations should be sensitive to small HR fluctuations and show patterns and trends across interlocutors. This may lead to better emotional awareness and empathy.

Heart Rate as an Implicit Context Communication Cue

Participants used heart rate as a subtle and implicit cue to determine each other's context. They often referred to the colors from *HeartBubbles* or *HeartLight* together with the date and time to guess their partner's location or activity. With regular use of HeartChat over the two weeks of the study, several participants were already aware of their partner's whereabouts or activities at certain points of the day if they sent messages. They often used this information to predict an upcoming interruption in the chat conversation (i.e. running to catch a bus). Participants mainly used *HeartBubbles* or *HeartLight* views to gain such contextual insights, since color coding allowed them to see the bigger changes in heart rate due to physical activity. One participant (G6P1) suggested further augmenting the message bubbles with emoticons or animating the bubble to indicate movement. These findings show that subtle cues from physiological sensing can provide insights into a chat partner's context without disclosing the exact location or activity.

Design Recommendation: Using physiological information as a subtle contextual cue can be further encouraged by design. For example, animating the text message bubble or showing a fast beating heart could imply that the user is running without overloading the chat with extra information.

Persistence, Representation and Mode of Sharing

Our analyses of questionnaires and interviews revealed that most participants preferred the persistent nature of *HeartBubbles*, which provides a historical overview of the heart rate information in the chat. However, due to asynchronous chat conversations (i.e. responses might not come instantly), this misses out on opportunities of capturing the desired *reactions*. Three of our participants mentioned that they would like to see the immediate reaction of their interlocutors whilst using *HeartBubbles*. For example, by knowing their interlocutor's heart rate when they actually *read the message* and not when they replied with another message. However, one participant (G3P1) stated that this defies the nature of the chat environment, where people get more time to *formulate* their reactions. Explicitly heart rate sharing (through *HeartButton*) was found to be clear and easy to interpret, but often also *awkward* and *strange*, in particular if done for no obvious reason. In contrast, implicitly sharing heart rate without control was not preferred when chatting with colleagues or people who are not close.

Finally, the real-time visualization of heart rate (*HeartLight*) was often found to be not useful or purposeful because the app showed heart rate responses from the interlocutor only if both were online at the same time. Several people would have liked to also see their interlocutor's heart rate when they were offline – to trigger conversation, or just to *check on them* (G5P1) without having to talk. This awareness effect of silent heart rate sharing was previously discussed in the literature [27] and was found to also be redundant by some participants.

Design Recommendation: Control over the sharing policy is a preferred feature in systems which use physiological information. In addition, capturing real-time feedback whilst reading messages in a chat may make the chat experience more seamless and may increase flow of conversation.

PRIVACY AND SOCIAL CHALLENGES

Our work illustrates that sharing physiological data such as heart rate may create a more transparent communication channel than using only text messages. However, physiological signals can rarely be consciously manipulated to convey a certain expression. Hence, sharing heart rate may create issues in terms of managing one's own social presence i.e. one's *staged* expression (cf., Goffman's research on self presentation in everyday communication [12]). In other words, implicit physiological signal sharing may create an image of oneself different than desired. Walther's work on computer-mediated communication describes that users utilise properties of interfaces and channels to favorably influence the receiver's impression [36]. These aspects need to be considered in the context of heart rate sharing. Reflecting on our design of HeartChat we notice that we implemented two implicit and one explicit heart rate sharing modes. In our evaluation, users stated that they would use the explicit sharing with more distant persons and implicit sharing with people they are closely connected to. However, we did not investigate control options and ways to visualize implicit information in the work at hand. Yet, we recognise that these questions need to be addressed in future research.

More privacy and control can be achieved in several ways. Users can be shown the heart rate (or other augmented information) before it is sent and be prompted for consent. This would allow the way the information is presented to the interlocutor to be chosen (e.g., using emoticons to depict heart rate instead of colors). Or, users could be allowed to manipulate the heart rate before it is sent — similar to the way users have complete control over which emoticons to send. As a result, the emoticon may not comply with the user's 'true' emotion.

The challenge lies in striking a balance between retaining privacy and enhancing empathy in augmented chat. We have observed market applications aim for more context and personalization and fail to find this balance. An example is the *message received/read* feature introduced in mobile chats (e.g., WhatsApp). In the very beginning, it was perceived as a form of social pressure (e.g., to answer instantly) and gave away information about whether somebody is currently using the phone. Subsequently, further control was added to provide more control and create a mutual way of showing information (e.g., the user cannot see the status of their interlocutor if they are not sharing their own state). The same challenge may arise for HeartChat. For example, even with explicit control options, some user may start expecting that other share their physiological data and, one day, it might become a norm to do so. This is similar to social networks where people today use their real names, while only a decade ago, it was common to use aliases, which now may seem odd, unprofessional, or even suspicious.

In summary, we believe the following aspects should be further investigated: control options for sharing (e.g., per message, chat, overall; opt-in vs, opt-out), manipulation of measured values, other representations (including user-selected/defined ones), and tailoring physiological data representation methods for the social context of the relationships between the users.

CONCLUSION AND FUTURE WORK

We presented the design, implementation, and evaluation of a heart rate augmented mobile chat app. Through a focus group and literature review, we identified design dimensions. We implemented three view concepts for visualising HR: *HeartBubbles* (a persistent history with heart rate color coded per message), *HeartLight* (a real-time ephemeral color coded representation), and *HeartButton* (a numerical representation).

A two week in-the-wild study with 14 participants showed that HeartChat supports awareness and empathy between interlocutors, acts as a context cue and promotes engagement and play in chat activity. We discuss our findings and provide a set of recommendations for designers of sensor-augmented messaging applications. We suggest that future systems should be sensitive to subtle physiological parameter changes to act as an emotional and context cue, encourage the use of sensing by design and empower users to fine-tune data sharing policies.

In future work, we plan to add customizable settings for HeartChat to allow users to tweak the sensitivity of shared heart rate information. We also plan to integrate the displayed heart rate information with other contextual cues such as location or activity to allow users to better discern the meaning of the shared heart rate. We plan to explore HeartChat in the context of group chats. We hope that our inquiry will inspire future efforts in uncovering the potential befits of sharing physiological data for enhanced social interaction.

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