# IntimaSea: Exploring Shared Stress Display in Close Relationships


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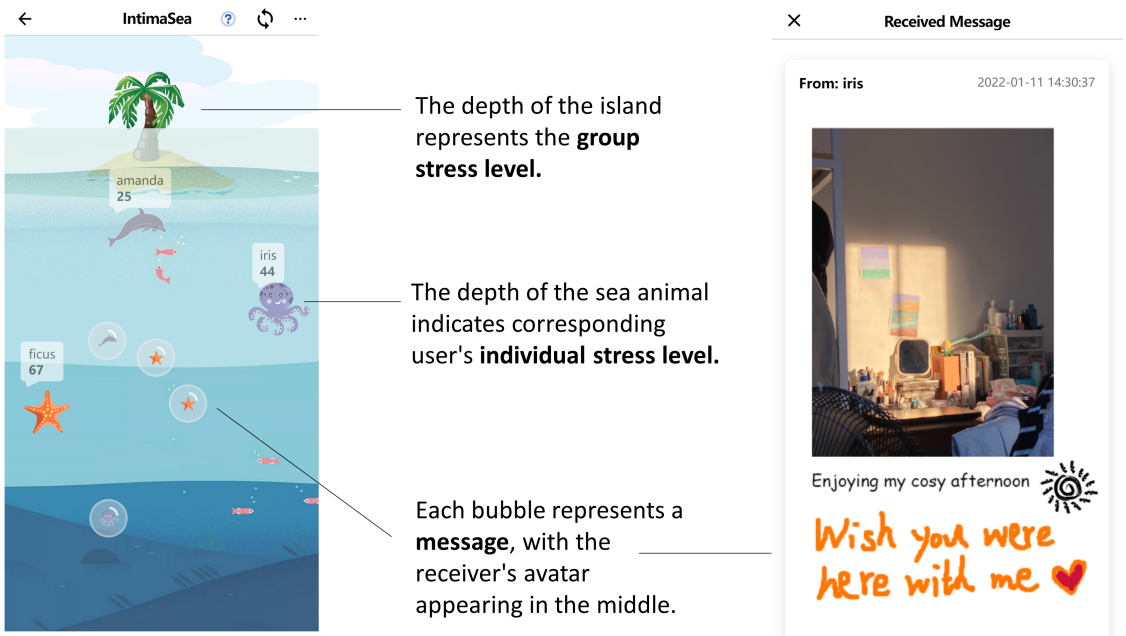


**Figure 1: IntimaSea is a shared stress display featuring illustrative, automatically sensed stress data in collective forms. By joining the same group, users can share stress data and interact with each other via customizable multi-media messages.**



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## ABSTRACT


Automatic stress tracking has become increasingly available on wearable devices. Research has investigated its use for individual




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stress management, largely within the traditional *data-as-care* framing. However, its use for stress sharing in social relationships, particularly close relationships, is still under explored. Inspired by the idea of "*caring-through-data*", which focuses on mediating the social and emotional experiences of the collective "us" with data, this paper presents a design study with a prototype called IntimaSea, a display featuring illustrative stress data in collective forms to be shared among close relationships. The field trials with nine groups of intimately-connected users (N=19) highlight its potential on stress awareness, interpretation and management, as well as intimacy promotion. We end by discussing sharing stress for social ways of stress management, stress data as a meaningful social cue mediating relationships, as well as design implications for *caring-through-data*.

## CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Empirical studies in collaborative and social computing**; **Collaborative and social computing systems and tools**.

## KEYWORDS

Stress, Stress Tracking, Shared Stress Display, Close Relationships, Intimacy, Caring-through-data

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## 1 INTRODUCTION

Today, stress-tracking technologies have been made increasingly available for everyday use, such as smart bracelets and watches produced by Huawei [59], Garmin [58], and Samsung [60]. By automatically detecting an individual's stress level [9, 80], sometimes combined with features to help with relaxation [15, 135, 138], they offer the potential to increase people's awareness of their stress levels and assist in daily stress management [127]. However, so far, stress-tracking is mainly explored for individual use, largely within the traditional *data-as-care* framing where self-tracking data is primarily utilized as a technical solution to wellness focusing on the "self" [26, 65].

Rather than focusing on individual use, this paper explores collective sharing of stress-tracking data among close relationships, informed by the approach of *caring-through-data* [65], which seeks to mediate the social and emotional experiences of the collective "us" through tracked personal data. After all, stress management is not merely a personal issue but also is deeply intertwined with social factors. Previous research has sought to provide informal social support to relieve the stress experienced by the patient's family [4], and use online support groups as stress management tools for teachers [79] and family caregivers [20, 27]. Although they focus on self-expressions, not digital inferences, of stress, it was found that, compared with the self-management of stress, this kind of more social and collaborative approach can mitigate psychological stress in a more effective and low-cost manner, as it can provide a sense of support, empathy, and encouragement [79]. We believe stress is a good indicator of when care and support are needed, and digital inferences of stress can potentially increase people's cognitive awareness of stress and facilitate stress-related expressions, thus sharing digital inferences of stress in social relationships is a promising direction to explore *caring-through-data*.

Among different social relationships, we are particularly interested in investigating sharing stress data in close relationships. Existing work on social sharing of stress data is mainly limited to stress visualization in workplaces [121, 131–133], explored as a way to raise awareness of the collective stress level [75, 97, 110]. However, as stress information is often associated with the impression of one's workload and performance, researchers typically adopt design strategies such as anonymity [133] and aggregation [121] to address privacy issues, limiting the feasibility of effective social interactions to cope with stress. Close relationships, according to Kelley and Thibaut, are defined by the profound way in which the well-being and psychological processes of one individual resonate with, and are tied to, the same processes in another person [128], and can play an important role in assisting each other with stress management through active engagement [22], empathic responding [22], mutual communication [8], and conjoint coping strategies [8]. Meanwhile, privacy issues and peer pressure related to personal data disclosure are less sensitive in close relationships [16, 86, 115]. Therefore, when social sharing of stress data is concerned, close relationships provide an ideal context to achieve balance between the potential of social support and concerns of privacy.

More specifically, our study is conducted to explore research questions as follows. **Will stress tracking and sharing technologies be meaningfully incorporated into close relationships? If yes, what roles can they play? What design issues might arise, and how can we better design them?** To answer these questions, we first explored new kinds of shared stress visualizations among intimate relationships through a workshop involving both students with design background and end-users. The resulting design is a shared stress display called IntimaSea, which allows people to view the illustrative stress data in collective forms and leave customizable messages for each other. We then conducted two rounds of field trials: a 2-week pilot study [99] involving our own lab mates and their intimate partners (N=9), and a 4-week study with participants recruited from outside our lab, with more diversified backgrounds (N=10). Our study illustrates that IntimaSea was meaningfully leveraged for stress awareness, interpretation, and management in a more social way, as well as relationship enhancement.

The contributions of this work are multi-fold: (1) to the best of the authors' knowledge, this is the first exploration of sharing digital inferences of stress in close relationships; (2) we present IntimaSea, a shared stress display featuring illustrative stress data in collective forms as well as interactions through customizable multi-media messages; (3) we provide novel and nuanced insights into how IntimaSea supports social ways of stress awareness, interpretation, and management, as well as its role in mediating close relationships; and (4) we explore design implications and future directions for stress and intimacy research, including sharing stress

for data engagement, sharing stress as a social cue, and supporting *caring-through-data*.

## 2 RELATED WORK

### 2.1 Stress, Stress Sharing, Stress Tracking and Stress Display

There has never been a unified definition of the term "stress", although people often talk about it in everyday life, referring to psychological feelings such as tension, anxiety, and fear. In psychology, stress is a subjective concept that occurs when "a person perceives the demands of environmental stimuli to be greater than their ability to meet, mitigate, or alter those demands" [76], much similar to our common understandings. As such, stress is often detected through self-reporting in psychology [36].

Former research on stress sharing/disclosure mainly relies on this form of self-report or self-expression, such as verbal communication [32, 103], expressive writing [96, 117], status updates [91, 101, 137], and human-robot communication [7, 83]. However, they face various challenges including lack of cognitive awareness of stress [78], lack of motivation [78], insufficient verbal abilities [93], and self-critical perfectionism [107].

Sharing digital inferences of stress seems a promising approach to address these challenges. In particular, stress is medically defined as "the non-specific responses of the body to any demand for change" [113], which is often related to physiological reactions generated by the autonomic nervous system (ANS), such as an increase in heart rate, respiration, and sweat gland activity [123]. When understood from this perspective, stress can be automatically detected and tracked using psychophysical measurements [30, 77, 118, 130]. Commercially available stress-tracking devices [58–60] often rely on an analysis of heart rate variability (HRV) to automatically detect stress. HRV, defined as the variation of time periods between consecutive heartbeats [1], has been confirmed as a reliable indicator of ANS activity [90] and an objective assessment of stress [70]. Many commercial wearable products use an embedded optical heart rate sensor to collect pulse rate variability (PRV), a less invasive but effective substitution for HRV [81], so that automatic stress tracking can be more easily taken into everyday settings.

Based on stress-tracking technologies, different kinds of visualizations have been employed to help people engage with quantified stress data. On Huawei's and Garmin's stress-tracking products, the raw data of HRV is converted to stress values within a range, and shown as bars with corresponding colors [26]. Besides conventional statistical style, researchers also have proposed alternative visual design styles to foster data engagement and understanding. For instance, Sun et al. [124] proposed and assessed five representative visual designs for guided stress management training, including raw numbers, bar charts, waves, butterfly drawings, and table lamps. Other visual metaphors [111, 126], artistic representations [135, 138], and ambient manifestations [89] are also used to improve the interpretability of the abstract stress data.

However, existing stress visualization approaches primarily focus on supporting the individual's mental cognitive process and stress management through biofeedback. Little attention has been paid to stress visualization/display in social relationships. Although there exist a few works focusing on the sharing of stress data, they are mainly limited to the workplace or controlled laboratory settings. For instance, Stepanovic et al. [121] developed a dashboard composed of aggregated visualizations of stress, but the primary purpose was to reduce health and safety risks rather than help with stress management. Other work along this line includes ClockViz [131], a clock visually augmented by projections of collective stress, and AffectiveWall [133], a shared display that provides a collective, anonymous visualization of individual HRV patterns. However, as they mostly set background in the workplace, researchers usually adopt design strategies such as anonymity [133] and aggregation [121] to relieve potential concerns about privacy and peer pressure, which limits the feasibility for meaningful interpretation and management of personal stress.

Although extensive research on dyadic coping has conceptualized stress management as an interdependent process between close relationships [8, 22, 64] through active engagement [22], empathic responding [22], mutual communication [8], and conjoint coping strategies [8], to our knowledge, few studies have explored sharing stress data in close relationships, which may be a more suitable scenario for sharing sensitive personal data [35], and hold potential for meaningful and effective social interactions to cope with stress. We address this gap by developing IntimaSea and conducting a field study of it in real-world settings to understand the meanings of shared stress data in close relationships, as described in detail in later sections.

### 2.2 Biosignal Sharing for Communication and Social Connection

While little has been done on sharing digital inferences of stress in particular, there has been extensive research on sharing biosignals, exploring issues of safety/privacy [46], use in particular domains such as gaming [23, 62] and sports [18], and design for particular type of biosignal such as heart rate [52, 87, 115], skin conductance [13, 56] and breath [38, 71]. Here we review the works of biosignal sharing that focus more specifically on fostering communication and social interaction.

Previous studies have mainly explored the social meanings of biosignal from two perspectives: *biosignal-as-information* and *biosignal-as-connection* [115, 119]. *Biosignal-as-information* is when biosignals carry information about one's physiological and psychological states. It typically involves sharing biosignal as a message, revealing or clarifying information related to personal experience, a.k.a. affective self-disclosure [119]. For instance, Significant Otter [87] supports romantic partners sending heart rate-driven otter animations to express their current physical and emotional states. Another example is Hint [56], a dynamic t-shirt with patterns that change color according to skin conductance. Pairs of participants wearing it expressed that skin conductance displays "help validate their feelings and show emotional engagement with others". The informational value of shared biosignals can also enhance motivation, performance and coordinative effort in social tasks [94]. Another perspective, *biosignal-as-connection*, is when biosignals promote feelings of interpersonal connectedness [52], presence [57], and reflection on humanity [119]. For example, the Heart Sounds Bench [57] can amplify, record, and playback the heart sounds of

sitters, thus creating a feeling of connection to the social world. Another study of BreathingFrame [71] also showed the feeling of sentimental connectedness and telepresence through remote breath signal sharing over an inflatable photo frame. In summary, these two perspectives both illustrate the expressiveness of biosignals as a social cue [84], due to its emotional and social nature [94].

However, there remain major challenges in sharing biosignals in a meaningful way. Sharing the accurate value of biosignal over text is often awkward and not understandable [86], therefore recent works have leveraged ambiguity to support interpretations and construction of social meaning [35], such as encoding heart rate into color of messages [52] or animated otter avatars [87]. However, too much ambiguity may cause confusion and even misunderstandings [56]. In addition, limited control over sharing discourages users from actively sharing biosignals, often due to concerns of privacy [86, 115] and judgment [53, 55], especially among more distant relationships [119]. These challenges suggest the need for further explorations in terms of the scheme of sharing and visual design for different kinds of biosignals. In this paper, we explored the collective sharing of stress-related interpretations of biosignals, hoping to contribute understandings of how it can meaningfully foster communication and social interaction in close relationships, and how to design for it.

## 2.3 Technologies for Mediating Intimacy

There has been a growing interest in designing technologies to mediate intimacy - a sense of relatedness - in close relationships. Hassenzahl et al. [51] reviewed artifacts intended for mediation of intimacy and summarized "six strategies to create a relatedness experience: awareness, expressivity, physicalness, gift-giving, joint action, and memories". Here we review those works focusing on supporting *awareness* and *expressivity*, two strategies we also employed in designing IntimaSea, to better ground our work.

Maintaining awareness of intimate others is one of the most common design principles used in mediating intimacy. Aiming at creating a peripheral and unobtrusive experience, these works often feature implicit communication and virtual presence. Examples of implicit communication are: (1) the feather, scent, and shaker that create "visual, olfactory, and tactile links" between separated partners [122]; (2) pairs of remotely installed appliances that synchronize with each other to indicate daily activities [129]; and (3) a touch-sensitive display that will vibrate and change color when the remote partner is composing a message [44]. Other works explore transmitting a sense of presence. Former research utilizes everyday physical objects such as picture frames [12, 39], mirrors [24], and jewelries [2] to convey presence. With the recent development of Information and Communication Technologies, video streams and audio records are also used to create the experience of being together [5, 73, 134]. For instance, Bedtime Window [73] uses a slow photo-stream and a real-time inking canvas to share presence in bedtime for long-distance couples. In addition, Ye et al. [134] attempted to support asynchronous co-dining between all family members through audio recordings. The emerging social virtual reality systems also provide new possibilities for immersive intimate experiences, such as embodied physical contacts and sense of co-presence [37, 136]. However, as suggested by previous research [24, 44, 129], this kind of awareness/telepresence technology should be carefully designed to strike balance between privacy and disclosure, and follow the design principle of ambiguity [40], otherwise it may bring undesired feelings of being monitored and overwhelmed.

While awareness represents a more implicit, ambient strategy of mediating intimacy, expressivity supports more explicit expression of affections, often incorporating enriched and playful communication channels. Expressivity can be achieved either through simple on-off signals (e.g., ComTouch [11], FeelLight [125], and Virtual Intimate Object [63]), or richer messages in the form of text [114], photos [17, 19], music [42], biosignals [87], tactile patterns [105] and food [41]. Among the channels supporting intimacy expression, mobile messaging apps play an increasingly important role, where people can engage in continuous "small talks" to maintain connection [100] and carefully craft messages to express affection for each other [66]. Intimacy is also embedded in secret codes and repurposed meanings of certain emojis [67] and the co-customization of soft keyboard [48] shared between close relationships.

In this paper, similar to Bedtime Window [73], we combine the strategies of awareness (shared stress data) and expressivity (message tapes). Nevertheless, what makes our work unique is that: (1) we explore a relatively new measurement of one's state, stress, as implicit information to bring cognitive awareness of intimate others; (2) we convey co-presence more symbolically and metaphorically, showing the avatars of intimate partners in a shared virtual space (see section 3.2), instead of directly using everyday physical objects or high-fidelity photos and audios.

# 3 THE DESIGN AND IMPLEMENTATION OF INTIMASEA

In this section, we present the design and implementation of our prototype IntimaSea. As mentioned, we focus on sharing digital inferences rather than self-expression of stress as in conventional methods, and intend to explore new kinds of shared stress visualizations in a close relationship context to support *caring-through-data*.

## 3.1 The Design Workshop

To design shared-stress display for close relationships based on stress tracking technologies, we conducted a design workshop. Our aim is to explore novel shared stress visualizations to mediate social and emotional experiences with tracked stress data. Through the workshop, we engaged with both students with design backgrounds and end-users, generated design schemes, decided on key features, and refined the final design.

The first step was a brainstorming aiming to generate design ideas and schemes. Four students with design backgrounds (N = 4, 1 female and 3 males, aged 22-28) were recruited and participated in the session via video conferencing. We first discussed different categories of visual representations, including statistical, illustrative, artistic and tangible. Participants then independently generated corresponding sketches for each style, and elaborated on the data encoding scheme to represent the variables available, including social members, stress data (HRV/stress levels), and last update

time of stress data. After that, we had a 90-min group critique session to explain design ideas, give feedback, and finalize the data encoding scheme for each design candidate. At the end of the session, we asked the participants to vote for their favorite design, two for each category. The voting criteria were: (1) easy for interpretation and understanding; (2) highlighting the patterns of stress; (3) not creating anxiety or judgmental experiences. Fig. 2 shows some representative candidates.

Next, we run a small-scale session with end-users to collect feedback and help us further refine the design. Four participants (N = 4, 3 females and 1 male, aged 23-29) were recruited via word-of-mouth from a local university. The 2-hour session was conducted in-person in our lab, where participants reviewed our design candidates and gave feedback. Several key insights emerged. First, participants felt it necessary for the design to be "*intuitive and easy to interpret*", and anticipated there to be "*a logical connection between the encoding scheme and the patterns of stress*". Next, they hoped the design would not "*provoke extra stress and anxiety*". They also suggested adding a channel for social interactions, as they envisioned that social interactions might further support stress management in the context of close relationships. Through discussions, the participants reached a consensus that the "sea world" of artistic style (see Fig. 2(c)) may be the most suitable design, for several reasons:

(1) The deeper under the sea, the greater the water pressure is, which represents stress in a straightforward way.
(2) Representing users with different marine animals living in the same sea area brings a sense of togetherness.
(3) The bright color and cartoon style can help relieve user's possible anxiety.

Based on their feedback and suggestions, we refined and implemented our final design for further explorations.

## 3.2 The Final Design and Implementation

The resulting prototype is called IntimaSea, a shared stress display featuring illustrative stress data in collective forms as well as interactions through customizable multi-media messages. To illustrate the user flow, Fig. 3 shows a hypothetical scenario of how a couple use IntimaSea.

*3.2.1 The Shared Stress Display.* The idea of visualization is drawn from the sea world (see Fig. 1(a)). We hope to provide a glanceable and comprehensible way to show the statuses of different users, by adopting the following visual encoding scheme. The depth of a marine animal maps to the user's stress level, in accordance with the variation of water pressure. The horizontal position of the animal encodes the last update time of stress data: the newly updated data appears on the rightmost side; the animal will gradually move left as time goes by, and stay on the leftmost side if the user has not updated stress data for more than a day. Furthermore, the depth of the island correlates with the average stress level of the whole group. The whole interface is in cartoon style, with bright and lively colors to bring aesthetic experience and reduce possible anxiety or other negative feelings.

Intimately connected users can share stress data by joining the same group, and choose their favorite marine animal to represent themselves (see Fig. 4(c)). At this stage, due to the time limit of implementation, each individual can only join one group by entering the group name in their profile page (see Fig. 4(c)). We will explore design to support users to join multiple groups in the future.

*3.2.2 The Messaging System.* We specially designed a messaging system, hoping the display can play a more active and playful role in supporting social interactions in intimate relationships. The interactive editor (see Fig. 4(a)) allows users to add text, upload images, and create freehand drawing, following the design convention of popular online sketchpads. We provide some resources to further enrich users' editing experience, e.g., sending screenshot of the "sea world" and stickers of marine animals to discuss stress-related issues, adding emojis and message bubbles to express internal feelings, as well as recommending jokes and poems and sharing multimedia content via QR code to cheer up others. After users have finished creating the message, they can send it to their groupmates. At the current stage, no notification is sent to the receiver. We hope to derive understandings of how to balance between timely awareness and non-disturbance from the field trial, so we leave notification settings for future explorations.

To ensure the consistency of the overall style and increase its visual appeal, the unread messages are displayed as transparent bubbles floating in the sea (see Fig. 1(a)). When a user clicks on the bubble, the corresponding message will be opened (see Fig. 1(b)), and the bubble will burst and disappear. To avoid overlapping, the position of each bubble is random, but the receiver's avatar appears in the center of the bubble to show whom this message is for. Users could access their past messages by simply clicking on their own avatars or going to their personal center (see Fig. 4(b)).

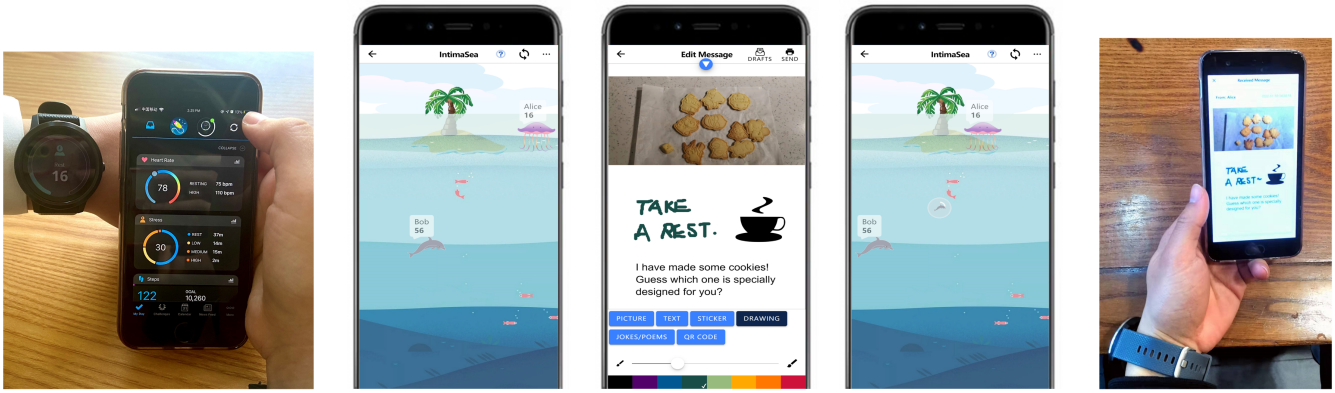
*3.2.3 Implementation Details.* For stress data collection, we decided to use Garmin products (watches or bracelets), as commercially available devices can be more easily taken into users' everyday life and allow user studies to be conducted in real-world settings. Garmin wearables offer all-day real-time stress tracking based on an analysis of HRV, which may be influenced by both psychological feelings and physiological reactions [34]. Its feasibility for stress measurement has been extensively investigated and approved [3, 47, 54, 102]. Thus, we believe Garmin's HRV-based Stress Score can provide a continuous and reliable measure of stress. In addition, the Garmin Health REST API makes it convenient to retrieve user's data, with an authorization process (see Fig. 4(b)). The returned stress data is in the format of average stress value in three-minute intervals. The stress value ranges from 1 to 100: 1-25 means rest, 26-50 means low-level stress, 51-75 means medium-level stress, and 76-100 means high-level stress. No stress data will be measured when the user is not wearing a watch or in the state of walking/running.

We implemented a server to receive and save user's stress data. Every time a user synchronizes health data with Garmin Connect (Garmin's mobile app) through Bluetooth, the data will be automatically uploaded to the Garmin health server, which then sends a Ping notification to our server for data retrieval. This mechanism ensures the near-real-time consistency of the stress data. Users' data is saved in a MySQL database for later processing.

For the frontend of IntimaSea, we built a website so that users can access our system from different kinds of devices. The message editor was implemented using a JavaScript library called *Fabric.js* [33].


(a) Statistical style (b) Illustrative style (c) Artistic style (d) Tangible style

**Figure 2: The representative candidates for each visual design style. They were later shown to end-users for further feedback and refinement.**



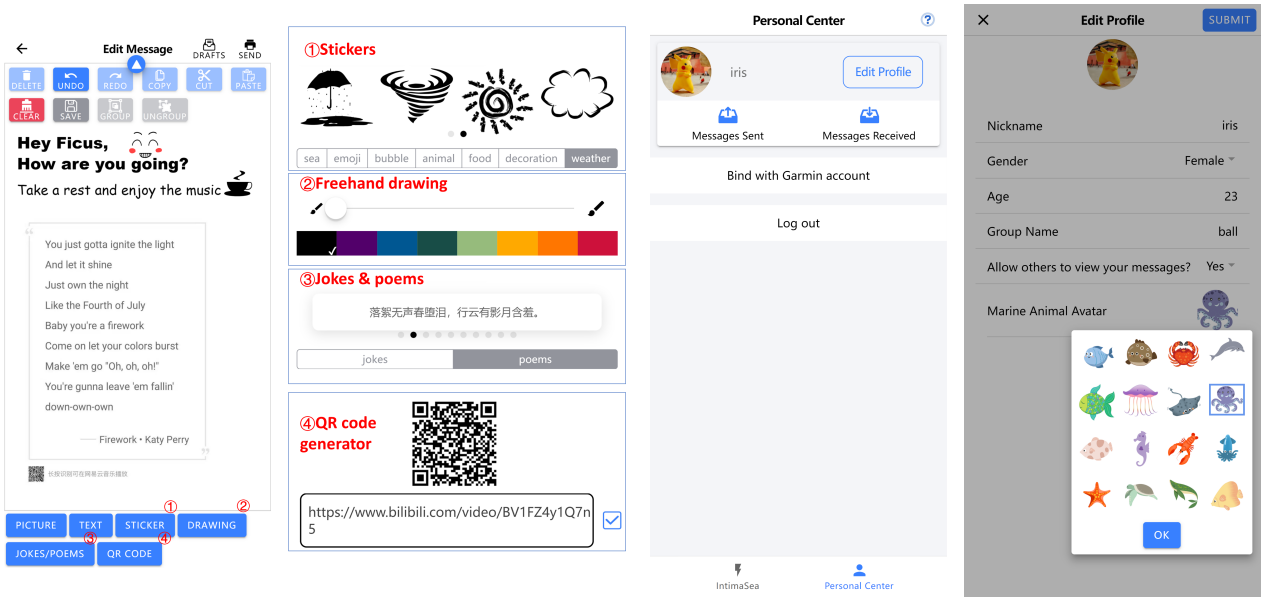

(a) (b) (c) (d) (e)

**Figure 3: A hypothetical scenario of how a couple use IntimaSea: (a) Alice took a glance at the watch and found her stress level had become lower than before, so she shared her current stress data with the display by clicking "sync" on Garmin's mobile app. (b) When opening IntimaSea, Alice noticed Bob's stress level was a little high and decided to send him a message. (c) Alice was composing a message tape to express her care for Bob. (d) Bob checked the display when he took a rest from work, and discovered the message (the bubble with a dolphin avatar). (e) Bob was viewing the message from Alice.**

*3.2.4 Privacy Considerations.* Given the sensitivity of stress data, we took privacy issues into careful considerations throughout the design process. First, we allow users to control when to share their tracked stress data, i.e., only when the user clicks to synchronize their stress data with Garmin's mobile app will their stress data be uploaded to our server, and the latest stress data will be shown on the display. In other words, if users merely view the stress data on their wearables, no stress data will be uploaded and displayed to others. Therefore, although automatic stress tracking technologies are used, users still could have some control of how to share their stress data. Second, users have no access to the stress condition of people outside their group or the raw data of their groupmates. The historical stress data of others is also not displayed for privacy concerns. Finally, users can set whether they allow others to view their messages on the profile page (see Fig. 4(c)).

## 4 THE FIELD TRIAL

The study is to explore the proposed design of a shared stress display within groups of intimately connected users. We deployed IntimaSea in real-world settings to establish its practical viability in the wild and to explore users' in-situ practices. Considering the sensitive nature of stress data, a two-week pilot study involving members of our research lab and their intimate relationships was conducted first [99], to develop initial understandings of whether our design of the shared stress display is acceptable and how it might be used in a close relationship context. Then, we run another round of four-week field trial with participants outside of our lab with more diversified backgrounds, to avoid potential bias and gain more generalizable findings. Overall, 9 groups and 19 participants were involved in the study, and the close relationships include couples, cousins, or close friends, where members feel close and comfortable sharing stress related information within the group. The demographic information of our participants is shown in Table 1.




(a) Message editor (b) Personal center (c) Personal profile

**Figure 4: The user interface design of IntimaSea: (a) message editor, (b) personal center, and (c) personal profile.**

In the rest of this paper, we will designate participants by A|B|...|I-[pseudonym], so as to give a sense of which group the participant is from. Below we will describe the user study in details.

## 4.1 Participants

In the pilot study, four groups of users (Group A-D in Table 1) were recruited via word-of-mouth. Among them, A-Yvonne, B-Ficus, B-Amanda, B-Iris, C-Eve, and D-Zoey are from our own research lab. However, except B-Iris who is one of the authors and extensively involved in the design and implementation of the whole system, all other participants from our research lab and their intimate partners had no former experience of stress tracking or relevant expertise on this topic, and had never used the prototype or known the details of our study before the trial. This pilot study acted as the first step to evaluate and understand the use of such a technology in everyday settings.

We then conducted a second round of deployment study with participants from more diversified backgrounds beyond connections with our own lab, to address any bias issues potentially introduced in the pilot study. We advertised our study by distributing recruitment flyers on WeChat[1], Moments[2], and WeiBo[3], searching for those who were interested in stress tracking and willing to share stress data with their intimate ones. Findings from the pilot study informed our participant sampling strategy: participants were unwilling to share stress among intergenerational relationships (see section 5.4.1), so the recruitment mainly involved couples and close friends. Finally, five groups of participants (Group E-I in Table 1) voluntarily participated in the study.

[1]A popular messaging App in China.
[2]Similar to the Facebook Timeline or the Twitter News Feed.
[3]A Chinese microblogging website.

## 4.2 Procedure

The two rounds of user studies followed the same procedures detailed below:

*4.2.1 Setup and initial interview.* Out of ethical considerations, we explicitly stated to the participants that the data we would access and analyze only included the interview scripts and the application usage logs, where the stress data would be kept confidential. After we obtained the participants' written consent, we provided them with an installation guide of IntimaSea, and offered technical help for any problems they encountered. We invited the participants to wear the Garmin device and then try to synchronize their stress data with our application, and encouraged them to leave a message tape for their groupmates. These practices intended to help them become familiar with IntimaSea.

After the setup, we conducted initial interviews with each group (all members together) for 40 - 60 minutes, either in person (Group B&D) or over WeChat voice calls at the participants' convenience. The initial interview aimed to introduce IntimaSea to them and find out about their existing practices of stress tracking and management, and their willingness to share stress data in close relationships. We also asked about participants' interpretations of the elements presented in the "sea world" of IntimaSea, to ensure they reached a consensus on how their stress data is encoded and displayed. Following our open-ended interview outline, participants in each group took turns to share their feelings and experiences with us, and they could add more details or discuss with each other before moving on to the next interview question.

We concluded the initial interviews by consenting participants, including clarifying that all the recorded data would remain anonymous and inaccessible to others outside the research team, and all

**Table 1: Participants. * denotes that the participant is from our research lab. The names of participants are pseudonyms.**

| Participant | Gender | Age | Education/Occupation | Location | Relationship |
|---|---|---|---|---|---|
| A-Yvonne | F | 23 | Graduate Student* | Shanghai | Couple |
| A-Alex | M | 24 | Graduate Student | Shanghai | |
| B-Ficus | F | 28 | Graduate Student* | Shanghai | Close Friends |
| B-Amanda | F | 23 | Graduate Student* | Shanghai | |
| B-Iris | F | 23 | Graduate Student* | Shanghai | |
| C-Eve | F | 31 | Ph.D Candidate* | Shanghai | Couple |
| C-Tao | M | 32 | Programmer in a Startup | Guangzhou | |
| D-Zoey | F | 22 | Graduate Student* | Shanghai | Close Friends |
| D-Wendy | F | 23 | Graduate Student | Shanghai | |
| E-Ning | M | 27 | Software Engineer | Shanghai | Close Friends |
| E-Bo | M | 27 | Operations Specialist | Shanghai | |
| F-Yu | F | 34 | Lecturer | Shanghai | Close Friends |
| F-Jia | F | 33 | Technical Developer | Dongguan | |
| G-Yi | F | 25 | Ph.D Candidate | Shanghai | Couple |
| G-Xin | M | 26 | Ph.D Candidate | Beijing | |
| H-Kong | F | 24 | Salesperson | Hangzhou | Close Friends |
| H-Li | M | 24 | Unemployed | Xinjiang | |
| I-Na | F | 29 | Operations Specialist | Shanghai | Cousins |
| I-Qing | F | 27 | Data Analyst | Shanghai | |

the participants could stop their participation at any time without consequence.

*4.2.2 Field trial.* During the trial period, we did not require any compulsory use, as we would like to learn about participants' usage in natural settings. Users were free to use IntimaSea at any time, and could feedback any usability issues or their feelings with us. To collect experiences before they forgot, we scheduled in-study interviews. We examined their usage logs, contacted each group to check if everything was working, learned about the details of their use, and probed them to share specific stories and experiences.

*4.2.3 Exit interview.* After the field trial, we scheduled exit interviews with the participants, following the previous joint manner. Each semi-structured interview lasted for approximately 1.5 hours. We used the usage logs and feedback we received during the trial period as cues to probe questions on participants' practices. More specifically, we leveraged the usage log to track participants' operations and investigated why they chose to use IntimaSea in that way. We also inquired into the participants' perceptions of the difference between the shared-stress display and the statistical data or charts provided by Garmin. In addition, we encouraged participants to reflect on their experience of managing stress with IntimaSea and the effects on building their relationships. In this process, some participants reviewed the message tapes or chat history on WeChat to help them recall the context and details. Finally, we asked whether they would continue using IntimaSea if possible and why, and what new features they would like it to have in the future.

## 4.3 Data Collection and Analysis

IntimaSea collected usage logs from participants on two main events: (1) When a user checks the shared stress display, the application will record the timestamp and the user's operations (e.g., refreshing the stress data; clicking the bubble to view the message). (2) When a user sends a message tape, the application will also record the timestamp and the targeted receiver. We performed quantitative analysis over these logs to understand participants' usages over time.

We conducted interviews in Mandarin but translated all quotes presented in this paper into English. We audio-recorded the interviews with the participants' permission and transcribed them for data analysis. For privacy protection purposes, we anonymized the participants' data. We performed thematic analysis [10] inductively on the interview transcripts and notes collected from the initial, in-study, and exit interviews of the two rounds of field trials. The authors first coded and analyzed the data independently, by reading the data and marking the ideas. Each then started compiling a list of codes. We then held meetings to discuss the ideas. Together we compared, refined, and consolidated the codes through iterative discussions of the most salient data, i.e., recurring patterns and surprising behaviors. We eventually curated codes into a set of preliminary themes and arrived at the findings as presented in the next section.

# 5 FINDINGS

As the findings we derived from the pilot study and the main study share similar themes about how IntimaSea mediated stress management and relationship building, and how our participants managed social boundaries for stress sharing, we decided to report them in a combined form to present a holistic picture of the key insights.

## 5.1 Overview

The log data showed that some groups (Group A, B, C, E, G) used IntimaSea more often - each person checked the shared stress display about 12 times/week and sent an average of 4 message tapes throughout the trial, whereas others used it less frequently - each checked our App about 9 times during the first week, and decreased to about 4 times/week afterward. As reported by participants, the reasons of their decreased use include the diminishing novelty, busy schedules (D-Zoey & F-Yu & H-Kong), chatting with each other on WeChat all the time (I-Na & I-Qing), and issues of critical mass [88] (some members in the group was too busy to check the App often, which also led other members not to check it as often). We find that those who experienced a higher level of stress or were separated geographically from their intimate ones showed more interest in IntimaSea and exhibited a more dedicated use. The reason is probably that people with a higher level of stress tend to pay more attention to their stress conditions, and people in long-distance relationships have fewer clues to learn about each other's stress, so this display becomes more valuable to them.

According to interview results, participants generally found that IntimaSea was easy to use and understand. In particular, compared with the stress visualization on Garmin Connect, which shows fine-grained, all-day stress conditions on a bar chart, participants liked the simple and straightforward representation of stress value on the shared stress display, and seeing "avatar sinking", not just an increased number, provided an extra push for them to take action and deal with the stress at the moment. In addition, they perceived the interface design of the shared stress display as beautiful and illustrative: the whole atmosphere was gentle and relaxing; the marine animals they could choose as avatars were cute and representative; the depths of the animals and the island were indicative of their stress conditions.

The two rounds of field trials yielded rich data on how IntimaSea might be meaningfully incorporated into close relationships for stress management and relationship enhancement. Below we will present more detailed accounts of how the shared stress display helped with social ways for stress awareness, interpretation and management, how it promoted social bonding and connection, and the social boundaries for stress sharing.

## 5.2 Mediating Stress Management

This section will elaborate on how the display helped our participants develop social ways for awareness, interpretation, and management of stress in close relationships.

*5.2.1 Social ways for stress awareness.* The study suggests that the shared stress display provides more opportunities for intrapersonal, interpersonal and group-focused mindful awareness of stress.

First, our participants acknowledged that the sharing behavior by itself increased their mindful self-awareness of personal stress levels, particularly because the sharing of stress data still requires manual operations at this stage, i.e., synchronizing the data recorded by Garmin wearables with Garmin Connect mobile app. A-Alex put it this way: "*It is the sharing of stress by itself that makes me more aware of my current state.*" B-Ficus would make intentional choices of when to update and share her stress, so she followed the changes of her stress value closely. Similarly, G-Xin made it clear that his sensitivity to stress increased: "*The system strengthens the impression that you need to pay attention to your stress... and affects your behavior unconsciously. This sensitivity was most valuable to me.* " As such, the sharing behavior itself became a pull that drew people's attention to their tracked stress, and more importantly, internalized their sensitivity to stress [94].

Moreover, the shared stress display also increased their awareness of intimate others' stress and promoted mutual understanding. I-Na admitted that the high-stress value of I-Qing gave her a more intuitive experience of I-Qing's feelings in quarantine, suggesting the value of shared stress data as a motivator of compassion and affective empathy [94]. Similarly, although A-Alex never expressed his stress explicitly in words, A-Yvonne found that once his stress value surged to 96 when studying for the National Judicial Examination (A-Yvonne knew in what particular periods of the day he was preparing for the examination). Therefore, A-Yvonne appreciated that the display provided another channel for her to understand A-Alex. Besides, the asynchronous nature of our system creates subliminal nudges for our participants to mindfully pay attention to each other's stress issues, as G-Yi reported:

> *For long-distance couples, it's important to stay in touch and know each other's emotional states. With the display, you know that your intimate one would share their stress data from time to time. This simple fact reminds you to keep an eye on any updates, and reach out to them when necessary.*

In addition, our design of the island, which indicates the overall stress condition of the whole group and also distinguishes our design from previous work on personal data sharing (e.g., [86, 87]), becomes another factor in drawing our participants' attention to their stress issues. The floating and sinking of the island often led to communications between group members or even taking action. For example, noticing the change in the island, G-Yi felt more strongly about the seriousness of their stress:

> *We were both having anxious moments recently, and the island was almost totally submerged by rising sea water...Actually it was a little scary...It was then that we were aware of the seriousness of our stress.*

As such, this symbolic design made them quickly notice a high collective stress level, leading them to take the stress issues more seriously than just seeing individual high-stress values.

*5.2.2 Social ways for stress data interpretation.* Our study also shows that the shared display provides more social ways to interpret and

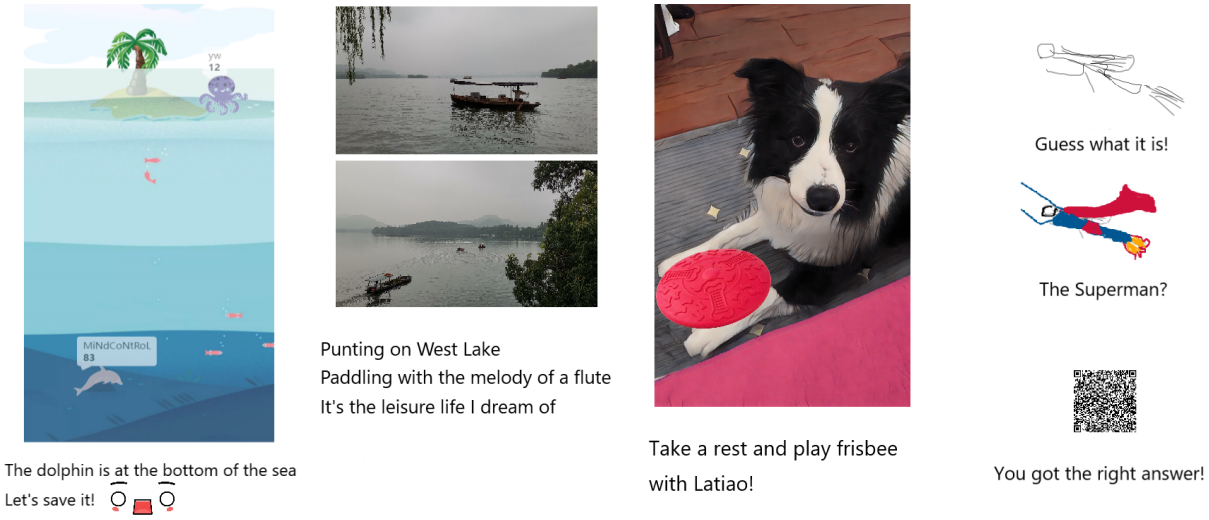



**Figure 5: A sampling of the message tapes our participants sent during the trial.**

make sense of the stress data. As shown in existing literature [26], the mismatch between the physiological-signal-based stress the device measures and the psychological stress users perceive often causes confusion and difficulty in interpretation, which would be a prevalent problem for automatic stress tracking technologies. Our study shows that sharing stress triggers conversations around the stress data and helps meaningful interpretations. Taking C-Eve as an example, she used to associate stress with mere psychological feelings such as tension and anxiety, so she was confused about her high-stress value once she felt relaxed after eating dinner. However, after a period of use of IntimaSea together with C-Tao and discussion with him, C-Eve started to make sense of it:

> *At first, we were skeptical about the accuracy of the stress data, so we did some tests intentionally. We found that eating meals or working out would make the stress value higher, so speculated that the device's stress detection might also be correlated with bodily reactions through discussion. Later we discovered Garmin could also detect blood oxygen level (which means it is physiologically related), and we paid attention to whether it had some relationship with stress value. According to my current understanding, stress is associated with three factors: fatigue in the body, blood oxygen level, and psychological feelings.*

Our study found that such a practice of comparing, discussing, and experimenting with the stress display was commonly shared among participants within the same group. F-Jia even hoped that the display could show the user's location or activity information besides the stress data, suggesting that contextual information could further support a social interpretation of stress. Although their understandings of the mechanism behind stress tracking technology were not all accurate, with other people's stress conditions as a reference, as reported by H-Li, they started to realize that "*what is measured is not simply psychological but also physiological stress*". It suggests that social sharing of stress has the potential to help people learn and form shared background knowledge for stress interpretation, providing social ways to address the challenges in meaningfully engaging with tracked personal data.

*5.2.3 More informed and considerate social interventions.* The shared stress display also enabled close relationships to play a more informed role in the (co-)management of stress, bringing more possibilities for stress intervention beyond self-management. As mentioned, the display provided an opportunity for our participants to discover others' stress when they were not staying together, and accordingly, they could take appropriate actions to support each other.

The timing of stress data was a primary factor for users to decide what actions to take. Outdated stress data was considered less representative, therefore it usually would not trigger immediate actions so as to avoid unnecessary disturbance. For example, when F-Jia noticed that F-Yu's high-stress value was updated last night, she decided to talk about it later when they both got off work. B-Ficus reported a similar case, where she adopted a less direct approach to express care by asking "*How's it going recently?*" instead of "*Why your stress value was so high then?*". In addition, after a period of use, I-Qing decided not to pay much attention to I-Na's high-stress value at around 8 p.m., because she knew I-Na would be exercising then. These cases revealed that among these close relationships, with their knowledge of each other's routines, showing the timing of stress data on IntimaSea invited co-management of stress among intimate ones in a more informed and considerate manner.

On the other hand, when they noticed that one's stress value went high unexpectedly in real-time, other group members could often offer timely help. For example, once G-Xin found G-Yi's newly-updated stress value had surged to a very high level, so he asked

her what had happened. Learning that G-Yi's recordings of experimental data was accidentally lost, G-Xin decided to help her calm down first, then shared his prior experience in such a circumstance:

> *As she was very frustrated and kept blaming herself, I decided to comfort her first. I told her:"It is quite normal to lose experimental data due to unintentional mistakes. The same thing also happened to me. What we can do is to adjust our mood and find a way to solve the problem. Now go home and get some sleep, and then look for possible backups. If there is no backup, take your time to repeat the experiment again. I will always be with you."*

G-Yi reported: "*I was so stressed to think effectively... G-Xin's words gave me the courage to run away from those negative emotions and face the problem directly. "* This case showed that the timely help provided by the intimate partner is valuable not simply in its instrumental value but also in it bringing back one's calmness and rationality in the sudden burst of emotion. When one got so stressed that they were at a loss for solutions, the intimate other who was still calm could often offer sensible solutions to the problem, thus could help intervene effectively.

Interestingly, the study showed that our participants would adopt different communication channels for different purposes. As mentioned, when the high-stress value was not up-to-date or could be expected (e.g., caused by concentration on work), a less disturbing way to help with stress intervention is preferred. Some participants appreciated the messaging functionality of IntimaSea as it did not send notifications or require immediate response, which may avoid extra burden on the receiver but still have positive effects. A-Yvonne explained why she chose to leave a message (see Fig. 5(a)) on IntimaSea rather than sending an instant message to A-Alex, based on her knowledge of his current status:

> *I did a bit of calculation of his update time based on the position of his avatar and found he might be studying then. I knew his stress was related to his concentration, so I would not interfere with his study. In fact, I left him a message because no immediate notification would be sent to him, so his study would not be interrupted.*

Similarly, B-Iris chose to pass on positive feelings to B-Amanda but did not want to interfere with B-Amanda's job interview, so she composed a message with scenery photos of West Lake[4] (see Fig. 5(b)), which brought B-Amanda a sense of relaxation when she discovered it later.

Meanwhile, Instant Messaging (IM) apps or voice calls were preferred to help address the issues, not merely to express care. These channels enable them to reach out to their intimate ones promptly and have more in-depth conversations about the causes of stress, especially when the high-stress value was unexpected. As mentioned above, when G-Yi was frustrated by the loss of her experimental data, G-Xin chose to communicate with her via voice call to learn about the details quickly and create a feeling of togetherness. E-Bo also explained why he seldom used message tapes:

> *When I checked the display and found something unusual, I would send the screenshot of "sea world" to our group chat and ask what had happened directly. It was much more convenient than communicating by message tapes. Afterall, composing message tapes on the sketchpad-like interface was burdensome, especially when it takes many rounds of conversation to explain causes and effects of stress.*

As we can see here, while the communication channel on IntimaSea was often used to convey care, channels such as IM were handier for a discussion for practical solutions. Our participants suggested that the shared stress display could be better integrated into existing tools, e.g., setting it as a chat background, so that it can become a part of the user's daily practices and help with stress management more conveniently.

Finally, the overall stress level shown in the display also figured into the way for users to manage their stress collectively. When our participants discovered that their collective stress level went high, they would engage in co-management of stress by chatting or relaxing together if possible. For example, when C-Eve and C-Tao noticed that the island was almost totally submerged on display, they decided to leave their work aside for a while. Although distant, they went for a walk together remotely and chatted over voice calls for 50 minutes. They reported:

> *We talked about our recent experiences and recognized we were just too busy working recently. We need to relax, and we have not met each other in person for a long time. So we planned a trip for the upcoming vacation. After the chat, we both felt much better and more motivated to balance our work and life.*

This quote suggested that intimate partners' co-participation in some stress-relieving activities could be very valuable as a social intervention for stress, due to increased motivation, sense of responsibility and coordinative efforts in dealing with stress issues.

## 5.3 Mediating Relationships

Apart from assisting in stress management, IntimaSea was also leveraged to promote bonding and connections in close relationships, mainly through three mechanisms: some unusual stress values provided our participants with a ticket to start conversations; the island and animal avatars on display created a sense of togetherness even when group members were apart; the messaging functionality was utilized as a specialized channel to express intimacy and prepare surprises. While this aspect could be related to the social way for stress management, we found it has its value for social bonding and connection per se beyond just for managing stress.

*5.3.1 Ticket to talk.* Similar to what is found on heart rate sharing [52, 115], our participants also treated stress sharing as an opportunity to convey their emotional and psychological states to others. For those who had always been willing to express their stress to others (e.g., A-Yvonne), the screenshot of the shared stress display acted as "*a hint or some kind of evidence*" of underlying feelings. For those who were not used to expressing their feelings explicitly in words (e.g., D-Zoey), sharing stress data, as a part of self-disclosure, implicitly signals that the sharer desires communication and care, thus providing others with a talk ticket:

> *Actually it's a bit awkward to actively initiate a conversation to share my feelings. However, with the display, it's like to*

[4]A famous tourist attraction in China with natural beauty and historic relics

> *have the door open, waiting for someone to notice my stress and ask me what has happened. It always makes me warm and encourages me to talk about my stress and experiences.*

Indeed, stress data can "*save the labor of starting a conversation*" as commented by F-Jia, but E-Bo made it clear that "*social bonding and mutual understanding are things that really matter.*"

Although the conversation may be initiated with the stress value, it is not constrained to stress-related topics, as it also prompted other topics for bonding in general [31]. I-Na gave such an example:

> *The stress value is a starting point for a series of questions...For example, why did you feel stressed today? Is it due to busy work or poor sleep quality? What happened at work? Were you staying up late last night to watch the new tv show? These small talks are a natural way to exchange our recent experiences and bring us closer.*

*5.3.2 Sense of virtual togetherness.* Through the study, we found the marine animals representing groupmates and the island representing the overall stress condition created a sense of virtual togetherness. As similarly found in previous literature [98], our participants developed an emotional attachment with their representing animal. When G-Yi had not updated her stress data for more than two days and found her avatar disappeared, she felt a little panicked: "*It's like some connection has been broken. The two fishes ought to be together, but now one is gone...* " In addition, as a symbol of collective stress level, the island was seen as something to be protected and maintained jointly, as B-Amanda explained:

> *The island belonged to all of us... If there was an obvious change in its depth, I would report the change in our group chat as soon as I discovered it... To some extent, it was similar to planting a tree together in Ant Forest*[5]*. We have to work together to maintain it.*

Our participants even envisioned future design improvements to promote the sense of togetherness more. G-Xin anticipated to learn about the backstory of the marine animals and unlock more plotline over long-term use. B-Ficus suggested changing the whole background of IntimaSea to bring more visual salience on the collective stress level. The above cases show the value of joint representation of stress in promoting social connections.

*5.3.3 A dedicated channel for intimacy.* Compared to other more general communication channels, our participants took the display as a dedicated channel for intimacy. The non-disturbing nature of our messaging functionality made the communication process longer, but many participants drew an analogy between message tapes and letters or drift bottles, and utilized it as a channel dedicated to passing on intimacy and surprises. B-Ficus enjoyed it as it gave her something to expect, "*like discovering a treasure*". Moreover, our participants also emphasized that they liked IntimaSea because it was only for bonding and relaxing, not for other purposes. A-Yvonne considered communicating using IntimaSea was mainly for conveying care instead of information. G-Xin thought "*sending messages using IntimaSea more clearly exhibited my purpose of caring others.*" B-Ficus made a comparison between IntimaSea and WeChat to illustrate her impressions of IntimaSea as a place promoting moments of mental rest and reflection [50]:

> *We already have the stereotype of WeChat as an application that mixes work and life... Some serious, work-related topics would make me stressed, therefore I feel a little reluctant to view messages on WeChat. However, IntimaSea is a special place only belonging to me and my intimate ones. I know the messages on it are mainly about our life, or something interesting and relaxing, so I will open the application with a light heart.*

Also, the way to craft messages for their close relationships is also taken as appropriate to express intimacy and understanding. B-Ficus and B-Iris played Draw&Guess to test the tacit understanding between them using the free-hand drawing functionality (see Fig. 5(d)). H-Kong's case is also a telling one. She specially designed the content of the message according to H-Li's likes (see Fig. 5(c)):

> *H-Li loves dog very much. When I discovered that he was stressed, I guessed seeing his pet dog would make him smile and forget about worries. So I added a sticker of frisbee to the picture of his dog, hoping to cheer him up.*

Through this kind of messaging practice, with the conscious will of commitment, the dedicated time spent in crafting the message, and the understandings of the recipient, IntimaSea is turned from a tool to share stress data into a place to express care and intimacy.

## 5.4 Social Boundaries for Stress Sharing

The willingness to share often differentiates between social groups [31]. While our study mainly focused on exploring shared stress display in close relationships, participants also discussed sharing stress data among other relationships, such as family and working relationships, which helped us identify the social boundaries for stress sharing.

*5.4.1 Sharing stress data with whom.* One kind of relationship our participants tried to avoid is the intergenerational relationship. Former research suggested that shared personal data can break the traditional power hierarchy in a family and create tensions that blur the boundary. Therefore families may face challenges in negotiating a new boundary between connectedness and autonomy/privacy [104]. This intergenerational tension was perceived as an imbalance of power and prevented our participants from sharing stress data with their parents. C-Eve was such an example:

> *If my parents could see my stress value, they would call me to ask what was going on. Parents and children are not on an equal footing... If the child had a high-stress value, the parents would subconsciously cross the boundary, trying to help the child as people who have been down this road before but interfering with the child's life.*

Some participants also worried that sharing stress with parents would not produce positive effects, as they do not share the same context, so the data will not be meaningful or useful. G-Xin complained that his parents would only say "*It's no big deal. You shouldn't have stress.*" without providing any concrete help. F-Yu expressed her concern of bringing extra emotional burden to her parents:

[5]A project for climate protection where people are rewarded with "green energy points" each time they reduce carbon emissions. People use the green energy to raise a virtual tree together, and when the tree grows up, a real tree will be planted in a conservation area.

> *I feel reluctant to share stress with my parents. If they saw a high-stress value, they would kept worrying about me, trying to understand what had happened. As we live in very different environments, it takes effort to explain things clearly. Replying to their messages was tiring, but if I didn't reply, they would feel upset, or even lose sleep.*

For remote friends in relatively different environments who had not constantly shared recent experiences, our participants also considered sharing stress data less meaningful. B-Amanda, B-Ficus, and D-Wendy all reported such cases where it was too complex and demanding to provide the necessary background for in-depth discussions about stress with a remote friend. F-Jia also pointed out that it was difficult to strike a chord between people with very different roles and points of view. The shared stress data seemed less useful and even disturbing in this case.

Working relations are even more sensitive. While heart rate sharing makes people concerned about others' judgments about their physical state or fitness level [86], stress sharing is even more tricky because stress is often interpreted as an indicator of work performance. Our participants were concerned about the critical interpretations from other colleagues and bosses. There seems to be an interesting dilemma, as E-Ning put it:

> *If my stress value is high, others will think I'm unable to handle my workload and start to question my ability. If my stress value is low, others will say: "We are all busy, but you seem pretty relaxed. Are you messing around?"*

D-Wendy would like to maintain a clear boundary between her life and work, and for her, sharing stress with colleagues might break this boundary because the data might be used to infer other information about her private life.

As such, the ideal relationship for sharing stress may have several characteristics: on a fair footing, sharing similar context, and intimate such as couple, close friends, and siblings, so that they can "*provide appropriate emotional and informational support for each other*" as C-Eve said. However, as shown below, even in the ideal relationship, sharers must strike a balance for data sharing not to affect privacy or bring extra burden while enabling social support [31].

*5.4.2 How to share stress data.* Stress was considered very personal and sensitive, therefore our participants expressed their privacy concerns and additional burden if stress data was shared automatically or in a fine-grained form. C-Tao considered stress extremely sensitive and should not be shared with anyone unintentionally. A-Yvonne was afraid of "*the feeling of being monitored*" if stress was shared automatically. She was also worried about "*the additional burden caused by other's care*" when she was busy working. In addition, sharing real-time stress data was also considered unnecessary, as H-Kong said, "*no one will check the display all the time*". It echoed the findings from other studies that the real-time stream of biosignal information could make people mentally overloaded and distracted [85, 126].

Instead, our participants would want control in how to share stress data. They perceived the current scheme of sharing by synchronizing with the Garmin Connect App as suitable because it allowed them to choose when to share with the group. However, as the display only showed the latest stress value they had updated, some participants complained about the constraints imposed by this design. F-Yu and F-Jia expressed that they would "*easily miss other's updates of meaningful stress values*". I-Qing also considered that there was a certain degree of randomness in instantaneous, isolated stress values, but the long-term tendency in stress data might become valuable for friends to identify one's signs of depression. Based on this feedback, and for the purpose of providing users with the opportunity to track the changes, we may consider providing an overview of historical stress data, and allowing people to subscribe to their intimate partner's stress updates with the user's permission.

## 6 DISCUSSIONS AND IMPLICATIONS

In the preceding sections, we presented the design process and field trial of our prototype, a shared stress display in close relationships. To our knowledge, this is the first study to explore sharing digitally inferred stress data in close relationships. From our study, it is clear that automatic stress tracking, while typically approached from a personal health perspective, provides a lot of promising design opportunities to develop social ways for stress awareness, interpretation, and management in close relationships. The study also highlights that the meaning of stress data can be more social and expressive - as a hint of one's underlying subjective feeling, and as an invitation for inter-personal communication and care. The field study of IntimaSea yields rich implications for design, not only for stress management and relationship bonding but also to improve the practices of *caring-through-data* as a wider area of research, and we will discuss them in turn below.

### 6.1 Sharing Stress for Data Engagement and Stress Management

Compared to other self-tracking data such as steps or sleep, stress is intrinsically more complex, involving not only physiological and bodily reactions [113] but also psychological and emotional responses [76]. As pointed out by Ding et al. [26], the mismatch between the scientific notion and everyday understandings of stress may present challenges for lay people to meaningfully interpret and engage in the digitally inferred stress data, including lack of immediate awareness, lack of pre-required knowledge, and lack of communal support [26]. These challenges not only add difficulty to stress data interpretation, but also hinder effective stress management.

The results from our study (see section 5.2) suggest that sharing stress data in close relationships could be a potential solution to mitigating these challenges. Through the shared stress display, our participants clearly exhibited social ways of stress interpretation and management: they became more aware of their own, others' and collective stress; they better interpreted and made sense of the digitally inferred stress data through social comparisons and discussions; they provided not only instrumental but also emotional support to help their partners manage stress.

Our study suggests design ideas to further support social ways of stress interpretation and management (see section 5.2). For example, we could provide built-in support for social comparison

(e.g., providing visualizations of personal stress trajectories of different members) or recommend stress-relieving activities that require the joint participation of intimate ones. Moreover, especially among long-distance close relationships, the addition of contextual information might also help with social interpretation of stress [86], via automatic integration of sensed location and activity data with icons beside user's avatar (e.g., whether at home, workplace or sport court; whether reading, eating, or running), if users consent to share. Finally, the visual design and symbolic signs could be effectively used to raise people's awareness and attention than mere numbers (such as the submerging of the island as in our case), and bring a sense of togetherness (showing as marine animals in the same sea).

Our study also shows that manual and automatic handling of stress data could have very distinct meanings for stress data engagement. While automatic tracking could save the labor of self-reporting and provide more objective cues [70, 127], manual tracking indicates intentional or conscious engagement [26]. What our study suggests is that, we could combine the strengths of both by supporting automatic tracking and manual sharing. This approach can support more cost-effective, convenient stress tracking; meanwhile, the sharing behavior by itself indicates people's conscious attention and internalizes their sensitivity to stress data.

## 6.2 Sharing Stress as a Social Cue to Mediate Relationships

Our study reveals that shared stress data not only supports social ways of stress management, but also works as expressive social cues to mediate relationships (see section 5.3). Recent years have seen more research attention turned to "how data is situated and meaningfully engaged with" in social relationships beyond self-knowledge or behavioral change narratives [29]. Among them, expressive biosignals, or "biosignals displayed as a social cue" [87], have been actively explored to facilitate digital communication [56, 57, 61, 86, 92]. As low-level, raw biosignals (e.g., skin conductance) are "inherently ambiguous and open to multiple interpretations" [86], increasing research attention has been paid to higher level interpretations of biosignals (e.g., interpreting heart rate as emotion avatars [87]). "Stress", a commonly used concept containing rich psychological, physiological, and social-cultural meanings, and closely related to one's well-being [21, 106], could be one such higher level interpretation of biosignals, evoking important and meaningful interpretations to mediate social relationships.

At the same time, stress is easily associated with value judgement [124], thus when leveraging stress data as social cues in digital communication, it is important to strike a balance between meaningful sharing and privacy concerns. It suggests that we should be more careful in terms of the context to deploy such a technology, e.g., more cautious design in workplaces where performance is a key feature [108]. As shown in our study (see section 5.4.1), stress sharing is probably more acceptable among people who are intimate and on an equal footing, paralleling findings from former research on location [16] and heart rate [86] sharing. In addition, an important consideration is to give users more control over their stress data. Our study shows that real-time automatic sharing in close relationships is still considered overwhelming and brings a sense of being monitored (see section 5.4.2). Therefore, being able to choose a group of users to comfortably share stress data with, selective sharing through manual clicking, allowing interactive data modification [31], or at least providing options to control the time and frequency of stress sharing, may be more sensible approaches of sharing stress data as social cues while preserving privacy. It is worth noting that, this agency/autonomy in data sharing adds a layer of subjective and interpersonal depth [69] to the objective data. Former research has pointed out that people might adopt a scheme of selective sharing to ensure the shared data is interesting, meaningful or beneficial to others [28, 31, 56, 69]. Our study revealed that stress sharing can be intentional and selective too due to reasons such as self-expression (see section 5.3.1). It suggests that while this type of tailored data might be less representative of one's psychophysical state, selective sharing is socially meaningful for the informational and emotional value it conveys. Future work can further investigate the complexities of manual sharing of automatically tracked data and their implications for social understanding of personal data.

The joint representation of biosignals as social cues is also an interesting topic to explore further. Previous research on combining biometric data from several persons to produce a collective representation has explored visualizing synchronicity in breath [95, 109, 112, 120], arousal [116], heart rate [43], and even brainwaves [25] to foster the feeling of connection, relaxation and social play. These works show that the joint representation of biosignals acts as a real-time social cue to reveal shared experience [43] and triggers indirect coordination for a common goal [95]. This is similarly found in our study (see section 5.2.3), although we use the "island" to represent collective stress level instead of synchronicity in the underlying HRV data. It attracted our participants' attention towards the group's overall state, and motivated them to keep the island floating through co-management of stress. That is to say, the joint representation of biosignals elicits a sense of responsibility and provides another channel for people to feel socially connected [95]. We hope future work on stress management, team collaboration, mindfulness training, etc. could benefit from this form of design and uncover new interaction dynamics in different settings and user groups.

Hall [49] distinguishes between high-context and low-context cultures to understand communications in different cultures. Borrowing Hall's notion, we can probably conceptualize biosignals into high-context and low-context signals. As shown in our study, digital inference of stress may be an example of high-context signals: close relationships with a highly shared context built upon daily information exchange seem to be a condition for users to meaningfully engage with the data and understand the social cue behind the data [35] (see section 5.2.3), whereas relationships with relatively different contexts, such as family or remote friends, are considered less desirable for stress sharing (see section 5.4.1). High-context signals, such as digital inference of stress, mean that interpretation of such signals relies on many shared contextual understandings, and the meaning is more dependent on the subtle or unspoken social cues behind them, especially when the signal is used to infer affective state; in contrast, low-context signals mean that information is communicated in a more straightforward way,

as its meaning is already clear in and of itself, such as blood glucose level. Distinguishing between high-context and low-context biosignals might help us better understand in what context biosignal sharing might be meaningful and how to design to support related practices.

### 6.3 Designing for Caring-through-data

As we have articulated in section 1, our study is one such effort to explore *caring-through-data* based on a particular type of personal data - digital inferences of stress. Former research has investigated the social and emotional value of sharing infertility-related self-tracking data in online communities [72], and how the remotely monitored blood glucose data brought about emotional complexities and social tensions in the co-management of diabetes [65]. As similarly shown in our study, the shared stress display offered new opportunities to promote empathy, compassion, care, and support in close relationships. It suggests to us that the value of sharing personal data not only lies in concrete suggestions or instrumental actions, but also lies in mutual understanding and emotional support when needed, especially in long-distance relationships where people hardly have any clues about others' status besides explicit verbal communication. Based on our study, we suggest design implications of sharing personal data to further support *caring-through-data*.

One design implication is that effortful communication could be leveraged for expressing care. Kelly et al. [66] proposed that the investment of effort into communication is highly valued and meaningful for the mediation of close relationships. When designing systems for personal data sharing, sending notifications can probably keep users informed of other's updates in a more effortless way, and be of more instrumental value. However, in our study, although IntimaSea was not specifically designed with effortful communication in mind, we found participants perceived others' awareness of their stress conditions as a symbol of caring, mainly due to the investment of time and the special attention paid to it. Our participants also made effort in crafting the messages to express their care and intimacy. This is to say, we can design mechanisms that require meaningful effort to support *caring-through-data*, such as waiting for users to discover others' updates and providing the channel and resources to craft their own elaborate messages.

Another design implication is creating a balance between timely care and non-disturbing experience. Notifications are often criticized for causing user interruptions [45], leading to a decrease in work performance and a sense of burden and annoyance [68]. Apart from notifications, real-time data sharing or broadcasting is also found to elicit anxiety and even more stress because people cannot help worrying about their own data or checking others' data constantly [65]. Our study echoed these findings: participants were very sensitive to the extra burden caused by sharing stress data in real time or receiving undesired notifications, so many of them favored the current non-disturbing design of sharing and messaging. When designing personal data sharing systems to support *caring-through-data*, especially in non-urgent situations, avoiding extra disturbance is important. We do not mean that notification mechanisms should be totally removed; instead, we argue for a better balance between timely awareness and avoidance of interruptions, e.g., by giving users more control of when and what kind of notifications they would like to receive, taking the user's stress condition, schedules and environmental information into account, and exploring context-aware [68] or sender-controlled [14] notifications. Also, recording the noteworthy and meaningful changes in user's data and letting users decide whether to share or express they want others' care, is another possible solution to helping balance between timely care and a non-disturbing experience.

## 7 LIMITATIONS AND FUTURE WORK

As an exploratory study, we have limits in terms of the stress tracking approach, the number and diversity of our participants, relationship with each other, stress condition, and the length of the study. Although the study is suggestive in terms of understanding the potential and design space of a shared stress display, we do not claim that our findings are generalizable to stress sharing in all close relationships and in other variety of settings. With automatic stress tracking technologies becoming more available for everyday use, it would be helpful to investigate detailed usages of shared stress displays across different relationships, diverse populations and various settings. Here we mainly reflect on two important directions for further exploration.

**Disentangle the complexities of stress.** As is shown in our study, the complexity of stress – involving both psychological and physiological reactions – makes it challenging for lay people to engage with the shared stress data and make meaningful use of it. Future work can further explore the impacts of this complexity on users' perceived accuracy and motivation to use, and we argue for more algorithm transparency/explainability to better support appropriate meaning-making of stress data in everyday settings. For example, we can make the underlying stress detection mechanisms more visible to users, and acknowledge the limitations of automatic stress tracking products in differentiating between physiological and psychological stress. We may also consider collecting contextual information (e.g., time and location) or allowing users to record their activities, so that we can analyze and display the possible sources of stress. In addition, inspired by the social constructivist theory of emotions [6, 82] which perceives emotions as both a product of neurobiological mechanisms and cultural artefacts evolving through social learning, future work may consider augmenting physiological measurement with introspective measurement or representation to explore the complexity of stress among different cultural groups.

**Make stress sharing an app-agnostic functionality and fit it into a larger ecosystem.** Currently, IntimaSea is still a standalone application. Although it brings convenience for research purposes, the shared stress display might face adoption challenges in real-world settings, considering the issue of critical mass (see section 5.1). Previous research [48] has pointed out that, by augmenting existing messaging apps with new functionalities, users can experience innovative forms of personal expression while preserving their familiar communication places. Our participants also exhibited similar usage patterns, e.g., sending screenshots of the shared stress display over WeChat (see section 5.2.3). It suggests

to us that, by developing plugins and extensions to popular messaging apps, we can integrate the features of IntimaSea into larger app-ecosystems, e.g., setting the shared stress display as chat background and integrating message tapes into existing message channels. This points to an opportunity to solve the common adoption challenge by utilizing the model of unplatformed design [74], and allow for observations on how stress sharing features might interact with other app functionalities and impact users' real-world communication practices.

## 8 CONCLUSIONS

In this paper, we contribute the first design and empirical investigation of sharing digitally inferred stress data in close relationships in everyday settings. With a field trial of IntimaSea, a prototype we designed and developed based on stress tracking technologies, which allows users to view illustrative stress data in collective forms and interact with customizable messages, we illustrated the valuable roles the shared stress display can play for stress awareness, interpretation and management, the instrumental and expressive support it can provide for relationship building, as well as the importance of maintaining related boundaries when stress sharing is concerned. Our study confirms that close relationships provide a promising context for stress sharing technologies to support *caring-through-data* practices, due to the important roles they play in individuals' mental well-being and psychological processes, and suggests future research and design implications to further look into this direction.

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