Everyday Space as an Interface for Health Data Engagement: Designing Tangible Displays of Stress Data

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Figure 1: Sketches of tangible displays by co-design participants to show stress data

ABSTRACT

Health data user engagement, particularly with stress data, remains a challenge despite the widespread use of self-tracking products, like smartwatches and smart bracelets. Stress data engagement is crucial to the early detection and intervention of long-term stress which could cause harmful health effects. This paper explores the design of tangible displays to enhance engagement with self-tracked stress data. We conducted two co-design workshops in which participants were invited to design and draw sketches of stress displays for three different contexts. The workshops revealed many innovative ideas for using everyday spaces and materials as an interface to structure user interactions with the data, aimed at increasing awareness of stress data and management strategies while addressing various concerns associated with how the data is displayed. By focusing on stress data, this study highlights important opportunities to use everyday spaces as an interface for health data engagement.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

KEYWORDS

Tangible display, Self-tracking, Health data engagement, Co-design

1 INTRODUCTION

Automatic self-tracking technologies, now widely used in commercial wearable devices (e.g. smartwatches, smart bracelets) [5, 27, 43], give us the opportunity to track various aspects of our lives, including our behaviours (e.g. eating and activity) and health (e.g. sleep and stress). They hold significant potential in terms of raising awareness and providing support for personal health management [2, 12]. For instance, automatic stress-tracking based on Heart Rate Variability (HRV) is now available in smart devices, allowing individuals to prevent prolonged exposure to stress that could result in adverse health effects [41]. Besides stress data, there are all kinds of self-tracked data available on smart devices. Some of these can be directly quantified, such as heart rate and steps, while others require further calculations and interpretations, such as HVR [15, 27, 31].

Although more and more self-tracked health data is becoming readily available to users, it is still quite challenging for laypeople to understand and make meaningful use of them [12, 15, 16, 28]. While automatic tracking is often viewed as a way to reduce the burden of manual tracking, it also has drawbacks for data engagement. For example, it may lead to reduced user attention that negatively impacts the effectiveness of tracking [11]. In addition, screen-based quantitative and analytic forms of visualizations, such as bar and line charts, are the primary means of presenting health data on smart devices. However, users are usually reluctant to use these analytic forms of information, which are often considered difficult to understand even for experienced self-trackers [13, 34]. Other forms of presentation have been explored to improve user data engagement, including visual metaphors, artistic representations, and ambient manifestations [32, 38, 46, 47, 52], but most of them are still screen-based, and how they will work in everyday life is still unclear. Our research question is: How can tangible display address engagement challenges associated with health data in everyday life?

In this paper, we address the engagement challenges associated with health data by exploring the design of tangible displays as means to leverage sensory and social interactions. We will focus on stress data in particular. In recent years, automatic stress-tracking, based on HRV, has become available on smartwatches, and yet its engagement and interpretation still pose great challenges to the end users [15, 28]. Compared to other self-tracked health data, such as steps and heart rate, stress data contains rich social meanings. It can be too complex to understand and, in certain contexts, it is highly sensitive to be displayed [37]. It indicates psychological responses and physiological reactions, which have a significant impact on

well-being, behaviour, health, and mood [29, 39, 45]. Stress-related illness is a significant health issue and incurs the largest healthcare cost in the UK with an estimated yearly cost of over £11 billion, 1 in 6 people report experiencing a common mental health problem (like anxiety and depression) in any given week in England [1, 33]. Therefore, although challenging, being aware of stress data is important as it can enable health professionals and patients to identify stressors, effectively manage stress through timely interventions, and improve overall stress management. By designing tangible displays for stress data, we hope to leverage physical and tangible attributes to evoke multi-sensory engagement [8, 20], and encourage social interaction for interpretation and management [17, 37, 51]. We look into artistic and ambiguous forms of tangible display to enhance user engagement and interaction with stress data, while mitigating discomfort in disclosing stress data in shared places [18].

To gather design insights and considerations, we conducted two co-design workshops using the World Café method [50]. We started with an informal and small workshop with 4 participants from our own research group to help shape and finalize the workshop procedure, which was then followed by a more formal workshop with 9 participants, recruited from different backgrounds. Because of the situated natures of human behaviour and user engagement with tangible displays [7, 44], we distinguished between three different design contexts: a personal space, a shared office, and a shared living space. Participants were asked to sketch their ideas for tangible displays for stress data for each context, discuss them with other participants, and answer a few questions from the Q&A sheet. Fluid fiber was introduced as one example of a metaphor for the design materials of tangible displays, as it, with fluids flowing in tubes, offers the flexibility and expressivity to show digital data in physical, ambient, and artistic ways to suit different contexts [30]. In the workshop, participants created a variety of tangible display sketches for stress data engagement in different contexts and provided all kinds of design considerations in response to the Q&A sheet.

What was highlighted in the workshops is that our participants not only focused on the design of the display itself but also considered the social, institutional, and physical environments, along with the properties of everyday objects and materials when designing the tangible display. This was done to promote stress management while preserving the delicate balance associated with data displays. In this paper, we will illustrate how they leveraged the rich meanings of everyday spaces/objects to structure and improve their engagement, interpretation, and management of self-tracked stress data. Their designs resonate with the idea of using everyday spaces as an interface for interactions, as envisioned in the field of ubiquitous computing. Simultaneously, they emphasize the importance of addressing the sensitivities, subtleties, and nuances associated with displaying sensitive health data. We discussed the broad implications of the interaction with stress data in everyday life and the potential for it to be applied to other types of health data and domains.

2 RELATED WORK

In this section, we will review related work on user engagement with different forms of data presentation. We focus on alternatives to traditional screen-based visualizations, such as ambient display, data physicalization, and data sculpture. We will also investigate how they have been applied to self-tracked data engagement.

2.1 Alternative Forms of Data Display

Ambient displays convey information through users' peripheral attention [36] , using physical affordances, such as shape, color, and movement, to relay information in a non-distracting and engaging manner [8, 20]. Ambient information and passive understanding are the keys to an ambient display. Ambient information focuses on how information can be relayed in the environment through peripheral cues, such as sound and light levels, while passive understanding refers to the delivery of information without requiring explicit effort from the user [8]. For example, *Physikit* offers the general public an opportunity to explore environmental data using reconfigurable physical ambient visualizations. These visualizations utilize movement, vibrations, air, and light to represent the environmental data in an interactive and engaging manner. Ambient displays open up new possibilities for user data engagement [19].

Data physicalizations, while not emphasizing ambient information or passive understanding, also try to represent data using physical matter rather than just computer screens or projected images [21]. Data physicalization involves transforming data into physical dimensions, such as color, shape, and material, leading to sensory and emotional responses from users [22]. Not merely limited to the sense of sight, data physicalizations can also convey information and emotions through touch, hearing, and even taste, to provide a multi-sensory and engaging experience for the user. In addition, data physicalizations can be integrated into the physical world and allow for active perception, making the information more accessible and easier to understand than traditional screen-based visualizations [22]. It is recognized that playful and aesthetically pleasing physicalization can trigger emotional commitments, while abstract representations can benefit task performance and reflection [6].

A specific form of data physicalization is called data sculpture or data-driven art, which is a growing field that encodes data through aesthetic features [19, 35, 54]. These artistic style displays not only present data, but also possess a sociocultural significance that goes beyond the mere representation of information as they incorporate abstract and artistic elements and impart a sense of ambiguity to the overall display. [19, 35]. In other words, data sculpture is a way to stimulate communication, interaction, education, and engagement among a group [8, 18, 54].

2.2 Self-tracked Data Engagement

Some of these alternative forms have also been explored for self-tracked data engagement. One common approach is to use ambient displays to show health data as bio-feedback. For example, *Delight* uses an ambient lighting environment to track users' stress levels as they engage in relaxation exercises [53]. Similarly, *MoodLight* is an interactive ambient lighting solution designed to improve stress management by promoting social engagement among university students, the lights' colors change in response to relaxation techniques (deep breathing, thinking about something calming,

etc.) or stress (thinking about recent stressful experiences, physical activities, etc.) [42]. *Element* is an ambient display of real-time physiological data (e.g. emotions) exploring various social interactions and collaborations around the display [14]. Most of these existing works are experiment-based and focus directly on people's interactions with the display or social interactions around it, less attention has been paid to how these interactions could be shaped by the spatial and social contexts of the display.

Tangible representations of self-tracked data, such as steps, have also been explored for better integration into everyday spaces for self-reflection. For instance, *LOOP* uses eight wooden moving rings to represent the step data collected from the activity tracker [40]. By balancing informative and aesthetic properties, its goal is to unobtrusively integrate real-time activity tracking data into the user's home environment. In an aesthetically pleasing manner, *LOOP* aims to facilitate serendipitous interactions with the step data and reflections on it as part of everyday routines. There is also work focusing on modifying everyday objects based on users' Fitbit data such as steps, to allow for more nuanced and embodied experiences [26]. For instance, an ordinary football table with small modifications is used to show tracked data on its surface to provoke a competitive participant who is a football lover, to "compete" against his own data. Here, the tangible form of representation, with its aesthetic or personally meaningful properties, is leveraged for better integration into everyday spaces and evoking embodied experiences. However, with a primary focus on activity data such as steps, the design considerations likely differ and are less sensitive compared to other health data, such as stress. This is what we will be concerned within this paper.

3 METHOD

To gather valuable insight into designing tangible displays for stress data and to ensure that they meet users' needs and preferences, we conducted two co-design workshops. During the workshops, we employed the World Café method, which is an effective and flexible method that can be modified to meet a wide variety of needs through small-group discussions in an informal and relaxed setting [50]. To make the concept of tangible displays more intuitive and comprehensible, we introduced fluid fiber as a potential design material at the beginning of the workshops [30]. Fluid fiber, with fluids flowing in tubes, offers flexibility and expressivity to show digital data in physical or ambient forms to suit different contexts. Specifically, its flexible structure and fluidity make it expressive of themes, such as life, emotion, movement, and change, which are appropriate to the expression of stress data. To help ground the design process, we presented a video showcasing artworks made with fluid fiber as an example and source of inspiration, but participants were free to explore any materials or forms for their design. The workshop's result shows that fluid fiber was highly inspiring and not constraining for participants' creativity with all kinds of tangible materials.

3.1 Procedure

Five components of the World Café method were used in the workshops: setting, welcome and introduction, small group rounds, questions, and harvest [50]. We first had a dry run of the workshop with 4 participants from our own research group, which was meant to help refine and improve the workshop procedures, this was followed by a formal second workshop. The procedures of both workshops were similar, but we made improvements to the second one based on feedback from the first. These improvements included a clearer rotation scheme so that participants would have a chance to engage with different people for each design context. Additionally, a Q&A sheet was introduced at the end of each design session as a way to document the thoughts behind the design sketches (Figure 2a).

Setting. Context is very important in shaping human behaviour and interactions [44], and thus, the displays needed to be site-specific because the site shapes what information is appropriate to display [7]. We identified three common contexts in which stress information might be relevant: a personal space, a shared office space, and a shared living space. In the workshop, we had three tables, each corresponding to one context. When participants sat around the table, they were asked to sketch a design of a tangible stress display for that particular context. Coloured pencils, pens, sticky notes, sketch paper, and the Q&A sheets were provided.

Welcome and Introduction. At each workshop, we began with a 10-minute introduction to present the problem of stress data engagement and then showed a video of artistic works being created using fluid fiber for design inspiration. This was followed by an introduction to the procedure of the workshop. Participants were asked to do the following tasks: (a) sketch their own design for each of the three respective contexts; (b) discuss their design with their group members to decide on the fundamental notions behind their design sketches; (c) finish the Q&A sheet for each context; and (d) vote for the most important notions discussed in (b).

Small Group and Question. Participants were divided into small groups at different tables, each representing one of the three contexts. In addition to drawing a design for each context, participants were asked to answer questions on a Q&A sheet to document their thoughts and the rationales behind each design sketch, e.g. *Where do you want to put the display? What type of data is shown in the design? (e.g. real-time, historical, individual, or group data.) Who should be able to see the display? Could you please describe your design? If there are any special effects (lightning, rotating, etc.) within the design, what are these effects for? Are there any interactions with the display?* The same Q&A sheet was used across all contexts to ensure consistency.

Participants then rotated and changed tables at the end of each round, so everyone could have a chance to design for each context and work in groups with different participants. During each round, each group created sketches based on the particular context, discussed, and marked notions that they considered important to their designs on sticky notes (Figure 2b). Each round was held for 15 minutes, with 10 minutes to draw, and 5 minutes for the participants to answer questions and discuss and mark key notions. They could choose to create sketches individually or as a group, although in our workshop, all participants created a sketch individually for each context.

Harvest. After all three rounds, in the spirit of the World Café method, the groups were asked to leave their sketches and sticky notes behind on the table [50]. The researchers then collected all the key notions from their sticky notes and wrote them on a whiteboard, after which the participants were asked to vote on the most critical

ones for each context, as well as the most significant ones for all contexts as a whole (Figure 2c).

3.2 Participants

The first dry-run workshop was with 4 participants within our own research group, whom we will refer to as PAs in the later part of the paper. The second round had 9 participants recruited from our social network at school, we will refer to these individuals as PBs. Prior to each workshop, we gathered the participants' demographic information and prior experience with self-tracked health data. Participants for the second workshop were recruited from our own University and came from different colleges, including the College of Science & Engineering, the College of Social Sciences, and the College of Medical, Veterinary & Life Sciences. They ranged in age from 22 to 32, with an average age of 26.9. The group included 4 males and 5 females. The nationalities of the participants were as follows: PB-1 and PB-5 were British; PB-2 was Omani; PB-3, 4, 9 were Chinese; PB-6 was Indian; PB-7 was Indonesian; and PB-8 was Spanish. Five of the participants had some experience with health tracking, for reasons of curiosity (PB-1), exercise (PB-2, 6, 9), and sleep monitoring (PB-4). The other four had not previously paid attention to their health data. At the end of the workshop, each participant received £10 in cash as compensation. The study had approval from the school's ethical committee, and all the participants read the participant information sheet and signed a consent form before the workshop. A limitation of this study is that the participants primarily consisted of research students.

3.3 Analysis

We employed inductive coding for the analysis of the sticky notes, Q&A responses, and voting data from the workshops. All of the data was digitized for easy reference. We conducted open coding separately and then had a group meeting where we discussed our generated codes and engaged in axial and selective coding. This process resulted in the identification of a central theme: using the everyday space as an interface to structure interactions. The subthemes focused on achieving balance and enhancing stress data engagement and stress management. Below we present our findings by elaborating on these themes.

4 FINDINGS

In the second workshop, "easy to see" was selected as the most important notion for the personal space (5 votes) while anonymity and privacy of individual data was the top choice for the shared office (6 votes). Discussion facilitation was the most important notion for the shared living space (5 votes). The Q&A sheet revealed pertinent information on the participants' various considerations and concerns, which we will elaborate on in the following sections.

Our findings are presented in terms of the two sub-themes that emerged around the central theme of leveraging everyday space as an interface for interactions: (1) enhancing stress data engagement and supporting stress management, and (2) achieving various balances for stress data engagement.

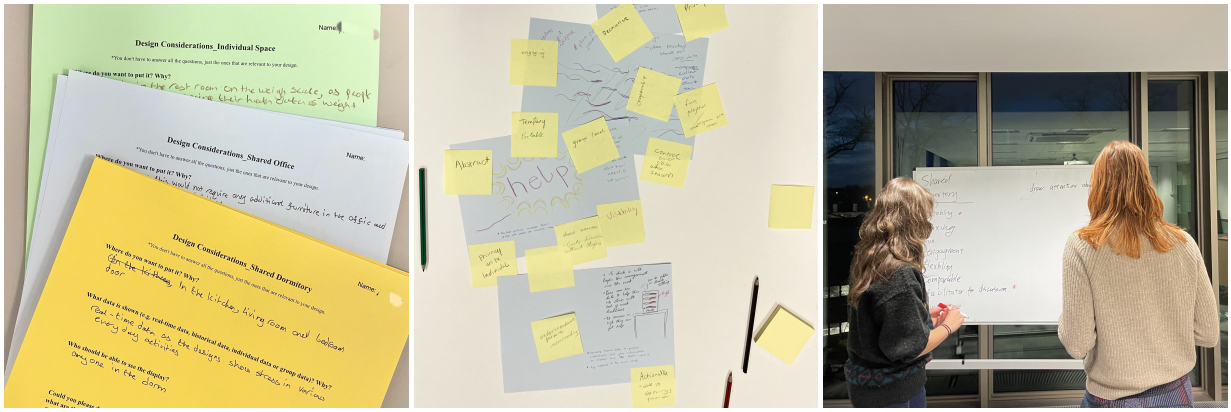
4.1 Enhancing Stress Data Engagement and Stress Management

4.1.1 Stress Data Engagement. In all the contexts, participants used the location to help engage with the data and shape user behavior. One example is to put the display in a place that is often associated with stress changes. With the display serving as an educational tool, users would be able to better understand the relationship between changes in their stress and other factors. For instance, PB-2 considered putting the display in the living room next to a TV to show each person's stress level while watching a scary movie (Figure 3a, upper right corner). PB-5's sketch (Figure 3b) put the display in the office kitchen because drinking coffee and tea cause stress levels to increase (as indicated by HRV) or next to the yoga mat which is about relieving stress. PB-5 explained, "*people [could] see the effect of the caffeine or could choose to not have coffee or go on a run, [do] yoga and see those effects.*" PB-2's designs were also to make the display more contextually relevant: a display for the shared office space only shows stress data during work hours (9am-5pm), and a display representing the stress data during sleep at home is placed on the bedroom door with different "z" shapes to indicate that the data was sleep-related (Figure 3a, lower left corner). With these designs, the displays would make it easier for users to comprehend how their stress levels changed, leading them to take appropriate actions. It would also offer a more comprehensive understanding of stress in a given context, allowing users to better manage it.

At the same time, participants strategically chose where to place the display with the aim of shaping people's encounters with the data. For the instance of office context, PB-4,7,9 put the display at the entrance to the company, right in front of the main door or at the top of the office hall respectively, so everyone could see it. Putting the display in a space that people needed to pass through ensures the data's visibility, increasing everyone's awareness of it.

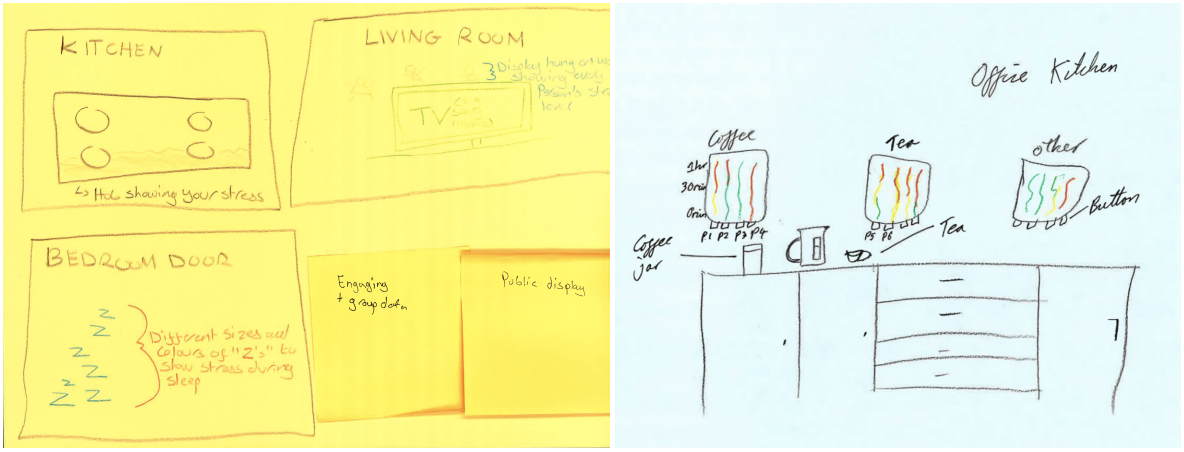
Additionally, participants took into account the portability of the display, which enhanced both its flexibility and accessibility to be integrated into different situations. With the portability and the ability to carry the display anywhere, users could conveniently access and view their data at any time and any place, providing more control over their stress levels. PA-1, 2, and 4 and PB-5 and PB-7 all emphasized the portability of the display, which made it easy to access. In particular, PA-4's design was a group of small-scale decorative ornaments that "could be naturally placed anywhere family/friends often gather." The tangible display's portability was also imagined to facilitate group discussions. For instance, by using portable displays to represent different individuals' data, the family could have a group conversation about a particular member's situation by picking up the particular display.

Moreover, "playfulness" was also commonly mentioned by our participants as a way to promote engagement. PB-7's design served as a wall decoration that allowed anyone whose data was shown on the display to change its color every week or month. This display also used a smiley face to show the happiest person of the month, which was meant to "*keep engag[ement] by gamification*". PA-1 suggested incorporating playful elements into the interface while PA-4 wanted to "*use the fun ways to show*". These customization options, interactive features, and visually appealing presentations



(a) Q&A sheets **(b) Key notions of design sketches on sticky notes** **(c) Voting for key notions**

Figure 2: The co-design workshop



(a) Display that integrated into a home environment where stress data may change **(b) The display in office kitchen showing stress changes associated with different drinks**

Figure 3: Contextually Related Stress Data Display

were thought to be playful and fun ways to enhance user engagement.

4.1.2 Stress Management. Participants frequently envisioned the display with the practical goal of stress management through an institutional, social, or individual approach. The institutional approach was commonly associated with the shared office and living space contexts. In these contexts, the display was designed and placed in a way that those with authority over the members' well-being would see it and be able to take action. For example, PA-3's design showed the overall group stress in the department's common room in order to make the bosses aware of when stress levels were too high. The hope was that help would be provided "*if someone was high [in stress].*" For the context of the shared living space, PB-4's design was "*placed in the manager centre [of university housing]...[as it was] designed ...for accommodation living.*" PB-4 thought of it as *"a mental health alarm, [when] the alarm rises, the manager [will] need to go and talk with the student."* It was also emphasized that the right to view the display would be restricted to relevant management personnel and students. For the context of shared office, PB-4's design provided a summary of the year as an objective measurement for a company or other workplace's management: "*it would be used as a parameter that will be checked every year to make sure the company didn't push the workers too hard.*" PA-3's design also combined the team's data to help protect employees by providing objective data and increasing transparency within the company. PA-3 wanted to help avoid overworking employees by using the display to "*give information on overall how the team's work is [going] e.g., indicating if the work is too much.*" As such, the display was designed to help gain an overview measurement, understanding, and management of the institution as a whole, and take timely action.

Others designed the display to foster mutual awareness and peer support in a shared space. In our workshop, the symbol of a face was

commonly used to represent data; for example, a sad face might suggest that a member needed help while a smiling face meant that the user was doing well. Faces were used in PB-7 and PB-8's designs for the shared office, and PB-8's design for the shared living space. PB-8 explained: "*The display uses different faces and colors to communicate how each person is doing in general terms, and if they have issues, the display shows it*". PB-8's design for the shared office emphasized a social awareness of the members' physical health. It had "*an exterior indicator if the worker was physically fine, or in need of medical attention...*", which "*allows people to support their office mates efficiently.*" In PA-1's design for the shared office, the word "help" and a symbol of "explosion" would come out if the stress level changed from "relaxed" to "medium", and "*the more people are stressed, the stronger the effect looks*". By using common symbols to represent the data, information could be conveyed simply and efficiently to attract the attention of others and to help those in need get help in a timely fashion.

At the individual level, additional visual cues to alert the user when needed were commonly used for timely interventions. In the context of the personal space, PB-3's design indicated high pressure through a change in brightness, and PB-9's design showed different colors in real-time when the data changed. This would make the important data clearer and more noticeable; therefore, users could respond quickly and take timely action. Furthermore, some participants' displays not only reminded users of important information about the stress data but also incorporated features to actively help relieve stress. For the shared living space, PB-7 wanted the display to play calming music for her and help her contact friends when needed. PB-9's design had a visually soothing effect, so "*[users] can change [their] feelings when [they] see the display, and maybe...change [their] stress.*" These functions, which directly addressed stress relief, could be a valuable addition to the display as they cater to users' specific needs, helping them manage and alleviate stress in real-time.

4.2 Achieving Balances

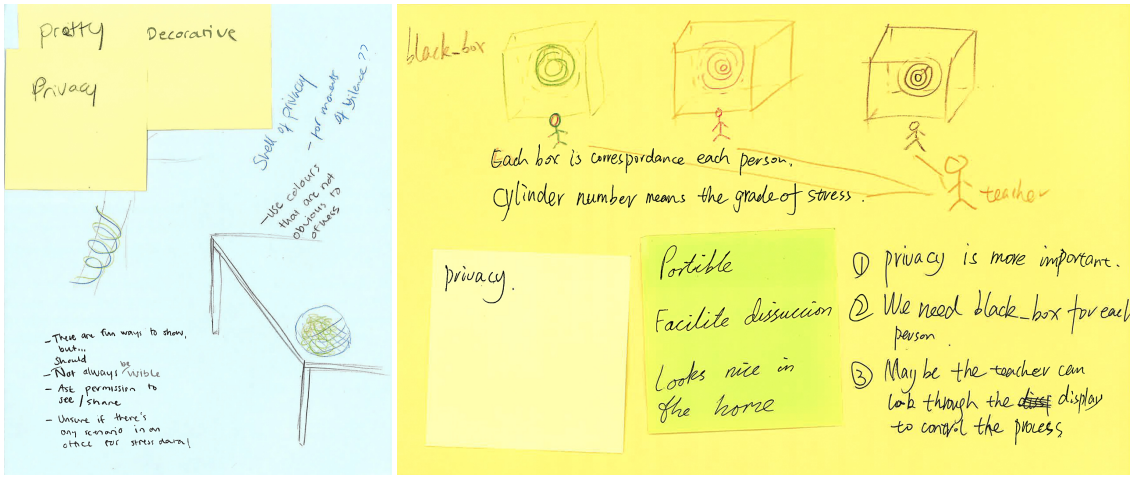
Our study also revealed tensions surrounding the displayed stress data. In particular, participants expressed three conflicting desires: raising awareness of the data but also protecting individuals' privacy; drawing attention to the data but not causing distractions; and representing the group as a whole while allowing a view of individual data. Our participants again leveraged the everyday spaces and materials to strike a balance in these conflicts.

4.2.1 Awareness and Privacy. Our participants all wanted the display to provide an enhanced awareness of their real-time stress levels but were also fully aware of the sensitivity of the data. Participants sought different ways to achieve a good balance or appropriate handling between the two. The most frequently used approach was a switch function that formed part of the design so that the display could be turned off. For example, to PB-6, a function that could easily turn off the display was an integral component of managing risk in all three contexts. For the personal space, he said: "*[I want to be able to turn on [and] off [the display], if I think there is any risk of the data being shared with somebody.*" For the other two shared spaces, he suggested that everyone in the group have the right to turn off their data on the group display. PB-4 and PB-5's designs had similar features. In PB-3's design for the shared office, she indicated that the participants should be "*able to hide their data.*" PB-9 even designed a stop button in the display for personal space. As such, a simple switch function would allow users to have control over their data and choose when to share it, even in their own personal space.

More interestingly, some participants leveraged everyday spaces and objects to achieve a more subtle control. For example, PB-1 situated her display called "*Flush Flow*" in a toilet in a shared living space and made use of the "flush" as a way to control when the data was seen. This way, a subtle balance between visibility and privacy was achieved as the toilet is something people use every day, thus forcing them to regularly interact with the data; at the same time, it is in a very private space to keep others from seeing it. PA-1's display for a shared office was designed to show the stress data only when touched, offering better control of when and how the data was seen. As PA-1 put it: "*[People] only see the current data [when touching it], otherwise [the data] remains hidden.*" In addition, some participants used physical barriers for data protection. For the context of a shared office, PA-4 used a shell for her display (Figure 4a), with colours that are not obvious to others as a way to protect privacy. "*It's not always visible*", and "*[people] need to ask for permission to see/share*,' she explained. PB-9 implemented a similarly secure method for displaying individual stress data in the shared living space of a student apartment (Figure 4b). Each individual's information was housed in a private "black box" that was only accessible to authorized individuals. These modes of hiding the data with different types of protection provided an added level of security for sensitive information.

For the shared spaces, participants commonly kept individual data non-identifiable for privacy protection. For instance, it was common to make individual data anonymous on the group display. For the shared office, PB-6's design showed colour-coded data that "*anyone can see [on] the big display [while] the personal data [was] anonymous.*" If a person wanted to see his or her own data, "*[they] received [the] data on their watch privately*". In this way, a shared group display and a personal device worked together but were used for different purposes. PB-4's design for the office was a two-dimensional display, with many circles showing the collective data of the company as a whole but with no data individually identifiable. This allowed users to gain a timely perception of the group's collective stress while, at the same time, eliminating concern for the disclosure of private data.

Using an artistic style to express data in an ambiguous manner was another way participants kept the balance between awareness and privacy. PB-5 designed an artistic display for the personal space that took the form of a lava lamp; the rate of the bubbles expressed the level of stress, e.g. fast bubble flowing meant high stress (Figure 5a). P5 described it this way: "*Everyone in the room can see the display when is turned on, but users could choose not to say what it is [to maintain] privacy.*" For those who did not know the meaning of the bubbles, the display was just an interesting and beautiful interior decoration. PB-1's design for a shared office featured an abstract art installation that resembled a flowing river (Figure 5b). The installation was made up of multiple fluid fibers, creating the imagery of a river and subtly displaying the stress data. Without knowing the purpose of the installation, outsiders would not know



(a) A protective shell for the tangible stress data display

(b) The stress data of individuals is kept confidential by storing it in a "black box"

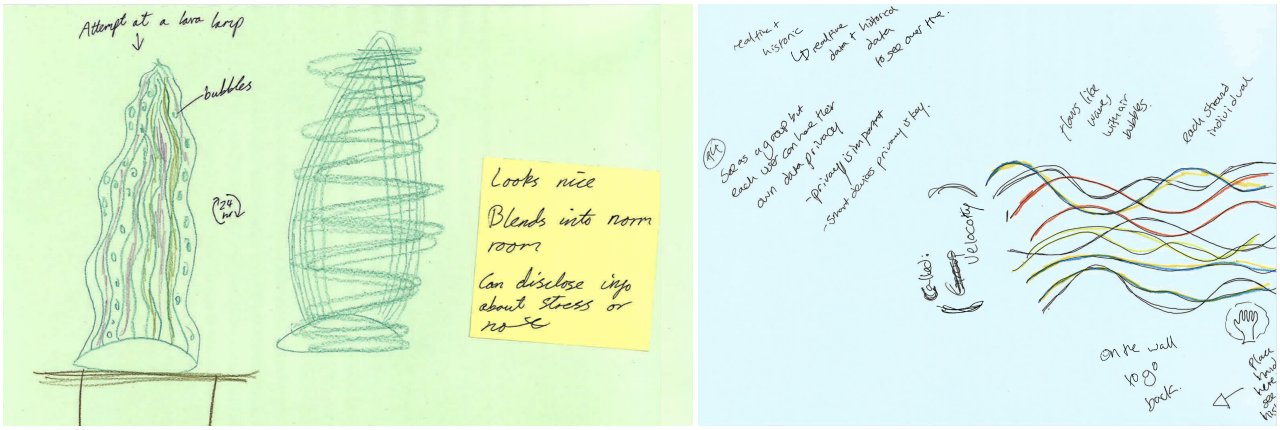
Figure 4: Physical Protection of Health Data

that it was displaying personal health information. With the use of an artistic style, the display could express data in an implicit way, therefore, protecting privacy without having to physically hide the data from outsiders.

4.2.2 Group and Individual. In our study, especially in the shared contexts, the participants all expressed a high interest in gaining an overview of the group as a whole while, at the same time, learning about their individual stress when appropriate. One technique to achieve this balance was the design of an organic structure based on individual elements representing individual data with the structure creating imagery of togetherness and unity. For example, for the shared office, PA-1's design featured intertwined fluid fibers, with each fiber representing an individual, but creating the visual impression of being together as a group. As described by PA-1, this display was designed to "*notice people as a group, [as] it flows like waves so it looks like [everyone is] flowing together*" Similarly, PA-2's design for the shared living space was a decorative piece that featured multiple layers similar to the cut side of an onion with each layer representing a family member (Figure 6a). In addition to providing a sense of togetherness through the structure, PA-2 also hoped that family members could compare stress data through this display, which was to serve as a reminder to take care of the mental health of loved ones. PA-4's decorative ornaments for the same context were even more inspiring, representing each family member's data as building blocks that could be assembled together to give a sense of oneness, e.g. when the family gets together (Figure 6b). In these ways, the displays could be used to represent individual data independently or the collective data of the group as needed.

4.2.3 Attention and quietness. While the display needed to be designed to draw users' attention to it in order to foster engagement and awareness, participants also emphasized that it should be "*calm and quiet, with no distractions*" (PB-2, in the context of the shared office). One approach was to integrate the display into existing everyday objects and environments to regulate interactions and achieve balance. For example, PB-1 integrated the stress data display into a clock, so she could know her stress level every time she looked at it (Figure 7a). PB-2's design for the personal space was to use the weight scale in the bathroom to also display the stress data, as "*people are already used to seeing their health data [on a scale].*" By integrating the display into the weight scale that he uses every morning, he also wanted to regulate the frequency of encounters with the data based on his everyday routine, such as viewing his stress data while weighing himself, to ensure a regular engagement. He explained, "*You can start your day with an understanding of [your] stress level.*" Similarly, in the context of personal space, PB-9 placed the display near his computer so it was easily within sight and "*[he] can see it anytime* (Figure 7b)." By integrating the display into existing everyday objects, data engagement also became a part of an everyday routine, demanding no extra space and little extra attention. For the shared space, PB-2 tried to integrate the display into an office desk, so it "*can easily be mapped to an individual, and does not have any special features that may distract workers.*" That is, by integrating the display into existing everyday objects, it could make users naturally aware of their stress data through their daily routines, without too many changes to their daily lives, or too much noise or distraction.

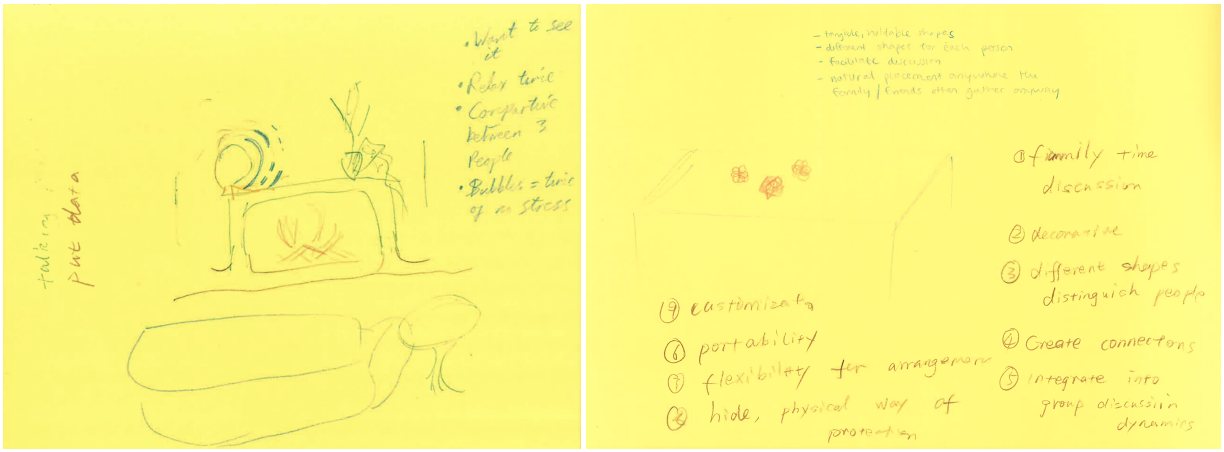
In addition, some participants' designs leveraged the nature of special materials and the aesthetics of an installation for easy integration. For the personal space context, PA-1 designed a lamp-like display to hang from the ceiling of a bedroom in the form of a cloud (Figure 8a). She explained that the display was meant to fit into the atmosphere: "*fluffy, using colour cues and colour filter (and soft colour), not conversational, not intrusive, soft, subtly, and making people aware.*" To her, using fluffy and soft materials conveyed a sense of gentleness, subtlety, and non-intrusiveness. Others emphasized the aesthetic beauty of their displays as a way for them to be accepted and integrated into existing spaces. For example, PB-5 described her lava lamp display as "*nice to look at and blend[ing] into the room.*" Similarly, PA-3 created a coral-shaped display as a



(a) Stress data display as a form of lava lamp

(b) Stress display as a form of waves

Figure 5: The artistic and ambiguous approaches to stress data presentation



(a) An onion-shaped display placed on the fireplace, each layer represents the stress data of a member

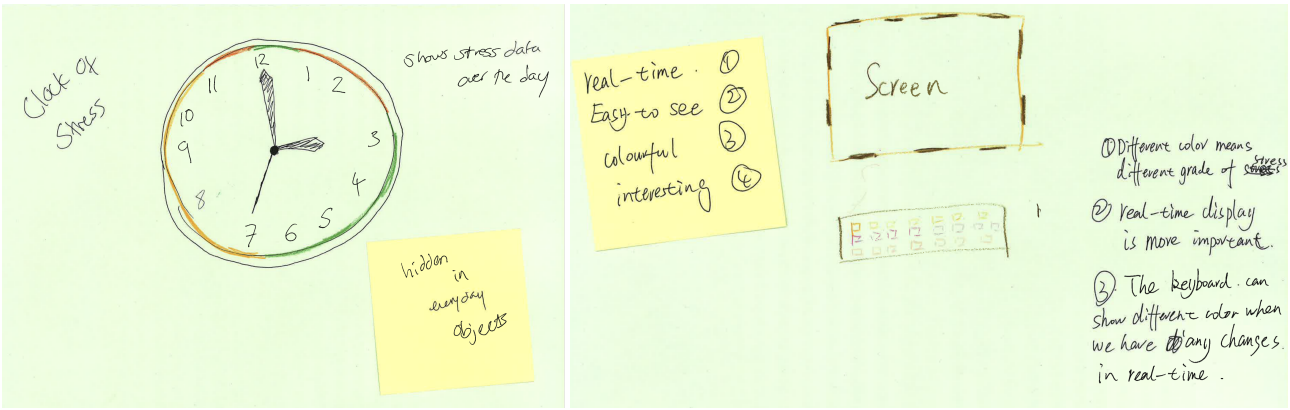
(b) Individual stress display blocks that can be flexibly separated and assembled together to present individual and group data

Figure 6: A sense of togetherness through structural display of group data

decoration to be put at the entrance hall of the home space (Figure 8b), and PA-4 designed a display that was a home decoration that could be placed freely throughout the living space. PB-3's decorative display for her bedroom was symbolically heart-shaped and two-dimensional, meant to show love, warmth, and emotional connection, aligning both with her design aesthetic and helping to create a comfortable and soothing atmosphere. These designs were tailored to the context, providing an unobtrusive way to display stress data while also serving a decorative function that enhanced the overall aesthetic of the space, allowing the devices to be easily integrated without further distractions.

5 DISCUSSION

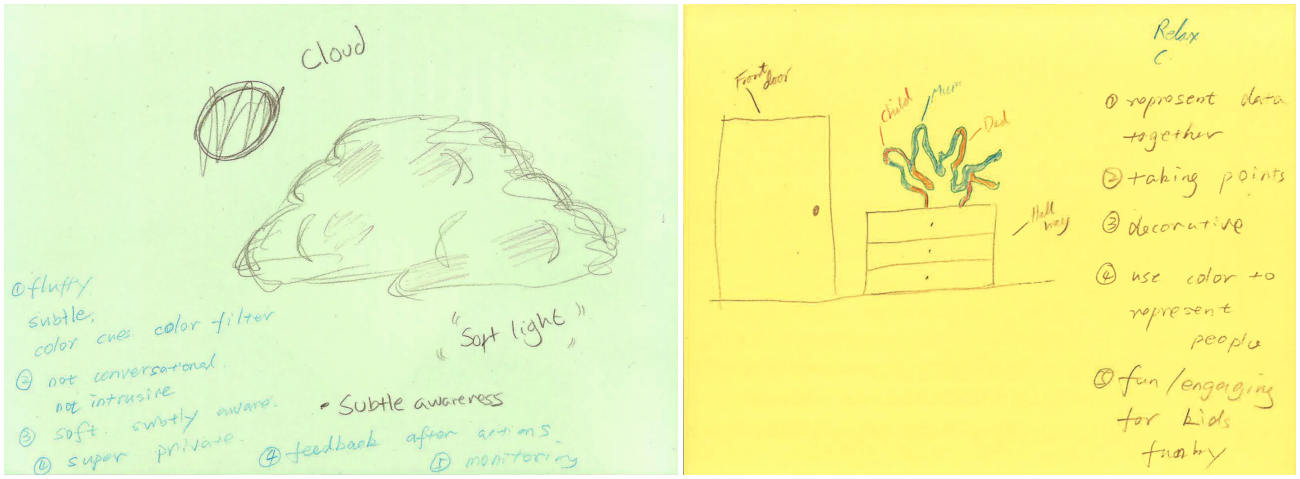
In the preceding sections, we presented our co-design workshops that explored designing tangible displays for stress data engagement. In our workshops, our participants did not merely focus on designing the display itself, but also carefully considered the nature of the situated space, the social and institutional environments as well as the properties of important everyday objects and materials. The intention was to create a display that could help engage with and manage stress while balancing the contradictory needs associated with it. The effective placement of the displays was crucial to these goals. The displays were strategically placed in high-traffic areas for maximum visibility and easy access, allowing individuals to quickly refer to the factors contributing to their stress levels. By presenting information relevant to the specific context, the display enhanced the user's ability to make sense of the data and engage with it meaningfully. The participants' designs took into account the institutional structure of families, companies, and dormitory administrators, as well as the nature of the space and the size and materials of the objects used. This helped to achieve all kinds of balances, e.g. toilet and flushing for awareness and privacy, barriers



(a) Integrate the stress display into a clock

(b) Integrate the stress display around a computer screen

Figure 7: Integrate the stress display into existing everyday objects and environments



(a) "Fluffy cloud" as stress display for warm atmosphere in the bedroom

(b) "Coral" as stress display and serve as entrance decoration

Figure 8: Artistic style stress display that fits into the space setting

for flexible group and individual displays, fluffy cloud representations for attention and calmness, etc. It reminded us of the old idea of leveraging everyday spaces as an interface for interactions, which has long been part of the vision of Ubicomp [8, 48, 49]. Our approach built upon this concept by taking into account the sensitivity, subtlety, and nuances involved in health data engagement, particularly with regard to stress data.

5.1 Everyday Space as an Interface for Health Data Engagement

As shown in this study, using tangible displays not only provides a new way to present data, but also situates new interactions shaped by the meaning of the object, the space, and the related social institution, ultimately suggesting new potential for health data engagement. Today, the automatic self-tracking of health data has become popular with wearable devices, such as smartwatches and bracelets. However, as noted in previous work [11, 15], it is still difficult for people to engage with it, and compared to manual tracking, automatic tracking can sometimes lead to decreased engagement and awareness [15], due to the fact that the automation of the data collection reduces users' involvement in the tracking process. By using tangible displays and embedding them into everyday spaces, we leverage the rich meanings, structures, and interactions that already exist in objects and environments as a way to promote, structure, and regulate our interactions with the data and achieve our various desires: awareness, privacy, comfort, management, etc. This is to say, if you just wear a smartwatch, you will likely not notice changes in your stress data on most occasions because you would only have an encounter with the data occasionally [15]; however, when you embed the display in a space where the data is highly relevant to the actions taking place nearby, like somewhere near a coffee machine, people can engage with the data in a more timely and contextually relevant way.

While the HCI community has long been interested in using tangible objects to foster interactions [8, 20, 37, 49], the focus has mainly been on sensory engagement while the subtlety of the situated meaning has not yet been fully explored. Previous work has paid more attention to using the physical properties of everyday objects to help people explore their data through their senses and enhance reflective processes, e.g. as a way to motivate behavioral changes by linking personal tracking with personalized everyday objects [10, 25, 26]. In our workshops, these materials and spaces were not only used to enhance sensory engagement and self-reflection but also to control the visibility of the data and determine who had access to it and at what times. For example, by embedding the display in a toilet, the users' interactions with the toilet also shape their interactions with the display. This transforms the toilet space into a regulating interface for data interaction, promoting the data's use in a more private and regular manner. Similarly, by integrating the stress data into a scale that people use every morning, users gain more structure and regularity to their interactions with the data while also achieving a balance among their desires for quietness, awareness, and privacy. In these cases, the meaning of stress data has been fully integrated into the rich meanings of the existing objects and spaces.

We are particularly concerned with user engagement with self-tracked stress data. Unlike general digital information, which has been the primary focus of previous work [8, 20], stress data is more personal and requires a higher level of privacy protection. Previous work, including the use of everyday objects, such as cards and books, and the transformation of architectural surfaces into interactive interfaces, has primarily focused on the seamless integration of digital and physical information. However, the sensitivity of the information and the delicate balance between accessibility and privacy has not yet been centrally focused. Our study highlights the importance of these considerations when it comes to more personal health data, such as stress.

The balance between the attention and the quietness of the envisioned displays, as shown in our findings, resembles the idea of ambient displays. Ambient displays, or peripheral displays, are meant to use our peripheral, not focal attention, to absorb information in a quiet way, through cues, such as background sounds and light levels [3, 8]. The information can then be leveraged by users to notice subtle and unattended details that signal internal states of being [42]. However, as shown in our study, for sensitive health data displays, not only quietness and attention, but other balances, such as privacy and visibility, individual and group information, are also crucial. Vogle and Balakrishnan have suggested providing techniques to discourage eavesdropping and allow users to control how their personal information is displayed [48]. Building on this, our workshops presented new means to reach these balances, including the careful choice of the space, the size, and portability of display (e.g. for easy hiding), as well as artistic and ambiguous expression [18].

Another driving force behind our study was the desire to enhance social interactions among users engaging with the data, e.g. putting the display in shared spaces. And this is exactly part of the design considerations we found in our workshops. In our workshops, we saw that our participants thought of the social environment for data interaction, interpretation, and use. For instance, when designing for shared living spaces, PA-4 suggested using portable displays that would represent individuals. She also envisioned the data being a conversation starter during family dinners, where the display could be brought to the table. The display was also commonly designed to represent group stress data, raise institutional awareness, and foster mutual care. As pointed out in previous work, this kind of social participation is crucial to transforming simple tracking into "knowing" and "caring" [15, 24].

Design to support a social means of health data engagement is, of course, not a new idea. For example, *MoodLight* is an ambient display designed to cultivate mindfulness and enhance stress management among university students by supporting their social engagement [42]. *Element* is also an ambient display placed at the workplace to foster social interactions [14]. However, while these examples focus on social interactions, the broader institutional structures and the implications of embedding these devices into social spaces have rarely been discussed. What is highlighted in our study is that, for the management of stress in a social institution, special institutional roles need to be taken into account.

While transforming everyday spaces into an interface is not a radically new idea, our study reveals more subtle and nuanced design considerations for self-tracked health data by using the rich meanings of the space to enhance and structure health data engagement.

5.2 Design Implications

The study suggests a number of implications for the design of tangible displays for self-tracked health data to be better integrated into everyday spaces for improved user engagement.

Placing the display in a contextually relevant space for situated engagement. We all know that context is key to understanding the meaning of content, and in our case, data. There has been quite a bit of work on how to help users make better sense of their self-tracked data. One particular approach is to integrate different data streams to give a better context for sense-making, e.g. blood sugar level data integrated with exercise and diet data [9]. In our workshops, however, we found that it is not through data integration, but by placing the data directly in a related context, that users are better able to develop situated engagement and more fully interpret the data, e.g. placing the display next to factors that might be highly related to changes in stress levels; showing the stress data in relation to a particular context, etc. If we want to integrate the display into our everyday spaces, then, we also need to think about what data should be displayed in which space for more meaningful engagement and interpretation.

Leveraging existing artifacts for interactions. In our workshops, our participants did not just create a new display, but embed the display in existing artifacts, e.g. toilet, clock, and bathroom scale, through which interactions were utilized to achieve engagement with the data as they desired. It was also a way for the display to be unobtrusive, that is, reach the balance between awareness and quietness, which emerged as a common theme in our workshops. Previous work has already drawn attention to using the meaning of existing artifacts to enhance engagement [25], and our study further suggests the situated nature of the artifact can help to achieve

many of the subtle balances involved in self-tracked health data display.

The choice of materials. The materials that an object is made of contain aesthetic features, evoke sensory engagement, and convey rich sociocultural meanings [54]. This is what data sculpture is about – leveraging these rich and tangible material properties to foster better engagement with abstract data. For self-tracked health data, we argue that the material properties play an even more important role in helping users experience their data. For example, one common theme that emerged from our workshops was that users want to engage with their stress data in a relaxing, playful, and fun way so that the interaction helps relieve their stress. This is to say that the choice of the material should not only help users engage with the data but also evoke a certain effect on them as they engage with it directly.

Size and portability of the display. Our study suggests that we should pay attention to the size and portability of a tangible display to help shape user interactions and achieve all kinds of subtle balances. It is known that a display's size can impact data exploration methods and efficiency. For example, a hand-sized physicalization can be visually inspected by turning it around, and a large-scale physicalization can be explored by walking around [23]. For large-scale visualizations, certain viewing angles may change the effectiveness [4]. Our study implies that portability can create rich interactions and social engagement. Our study also suggests that for personal health data, the size and portability of a display can allow for more flexible ways of data engagement, so that it can be taken into a private space, as shown in PB-5's design. All this points to the importance of taking into account the size and portability of the display for self-tracked health data engagement.

6 CONCLUSION

While automatically self-tracked health data has become increasingly available, and has great potential for enhanced awareness and early health interventions, it is still quite challenging for lay people to effectively engage with and make use of the data. This paper presents co-design workshops that explored tangible displays as a means to enhance self-tracked health data engagement in everyday life through sensory and social interactions, with a particular focus on stress data. The analysis of the workshops highlight the results that everyday spaces and objects can not only be used to help enhance engagement with data as commonly explored in previous work [25, 26, 40], but also used to help structure and regulate the interactions with data to achieve various balances, e.g. privacy and visibility, awareness and quietness and so on. More specifically, it points to the importance of paying attention to contextual relevance, the rich meanings embedded in existing artifacts, material choices as well as the size and portability of the display when designing for self-tracked health data for everyday life. After all, compared to general digital information, health data, such as stress levels, is more personal, subtle, and privacy-sensitive, and deserve more careful consideration than it's previously received.

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