AffectiveViz

Designing Collective Stress Related Visualization

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PROEFONTWERP

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Contents

Chapter 1

Introduction

Dory works as an accountant for a service company for two years. She shares an office with five colleagues from the financial management department in her company. She feels a sense of stress in her office from time to time. Sometimes she observed frown, sigh, and shaking legs from a stressed colleague that unconsciously made her feel anxious. Sometimes she feels helpless to cooperate with overtired co-workers during a scheduled meeting. Sometimes there is an awkward silence after a disagreement or an argument in her office. Sometimes the approaching project deadline occupies the team's social time... She is often bothered by these social stressors, which always involve other colleagues in her working environment. She wants to make some change. However she doesn't because sometimes she doubts whether the stress exists or she is just paranoid.

1.1 Collective Stress in the Workplace

The story describes one of the many possible collective stress scenarios in an office worker's daily working context. Collective stressors are common in organizations [Lansisalmi et al., 2000b]. When we mention *workplace stress*, we intuitively consider it from an individualistic point of view. And we think of it as a personal reaction to a specific occupational stressor. However, with the theories [Schein, 1996] in organizational psychology and sociology, stress is a cultural phenomenon of a situated and distributed nature in working environments [Kirkegaard and Brinkmann, 2016]. And researchers place emphasis on "the collective nature of stress experiences and coping" from an integrated view [Lansisalmi et al., 2000b].

The term “stress” is commonly used in our daily life. Literally, we vaguely understand it as a state of mind, a physical reaction, or an interaction between a person and the environment. Psychologically, Lazarus and Folkman define stress as a cognitive response to a threat that one perceives as dangerous or feels ill-equipped with in the environment [Folkman and Lazarus, 1984]. Such feelings are described as “distress” [Selye, 1956]. Rather, if one perceives such experiences as more excited than agitated, these manageable challenges become “eustress” [Selye, 1956]. Physiologically, stress is a state, when our homeostasis is challenged by internal or external stimuli (termed “stressors”) [Chrousos, 2009]. Unfortunately, all stress hurts. Even eustress, which is not psychologically harmful, is still a threat that could be detrimental to our physiological health [Kersten-van Dijk, 2018]. Stress has links to all leading physical causes of death [Cohen et al., 2007]. Therefore, stress needs to be noticed and managed.

The phrase “collective stress”, as one kind of stress, is initially defined in Barton’s work as the stress that “is created when there is a large unfavorable change in the inputs to the system, its subsystem and/or the micro systems within it” [Barton, 1969]. Sarason summarized it as “a phenomenon that the system cannot satisfy the basic requirements for a social group” [Sarason, 1970]. These definitions of collective stress are considered within a communities-in-disaster scenario and the stressors are highly contextualized (e.g., flood, earthquake, tsunami, economic crisis, etc.) In the workplace scenario, “collective stress” is considered as a cultural artefact [Fineman, 1995], that happens “when members of a particular organizational culture as a group perceive a certain event as stressful” [Lansisalmi et al., 2000b]. Current research points out the need to foster stress and the need for coping beyond the individual, and explore stress in teams and organizations [Rodríguez et al., 2019]. The “collective stress” discussed in this thesis is of the second type. We put our focus on the “occupational, workgroup-level stress” that appears in daily workplaces and organizations, rather than the “macro, post-traumatic stress” in catastrophe psychology.

Coming back to the workplace scenario, just like Dory experienced in the narrative story, collective stress comes either from other people (e.g., the facial expression from a colleague) or from a shared stressor (e.g., an approaching deadline for the team). Collective stress has been explored in the field of social psychology, such as organizational stress climate [Lansisalmi et al., 2000b, Kozusznik et al., 2015], emotional contagion [Hatfield et al., 1994, Teuchmann et al., 1999], stress epidemic [Wainwright and Calnan, 2002], and person-environment fit [Edwards et al., 1998], to name a few. Along these research lines, it is implied that collective stress commonly exists in the workplaces, and that the stress can be transferred from one person to another. It echoes with the externalism of stress in [Kirkegaard and Brinkmann, 2015], which describes how the stress can be embedded in the shared environment and how it can generate repercussions at the organizational level. Together, collective stress is not only an unbalance for the individual's physiological health, but also potentially harmful to the whole working environment. Therefore, aligning with the socially distributed characteristics of stress, collective stress should be noticed and coped. The impact of social context and interpersonal interactions should be taken into account and discussed meanwhile.

"Coping" is defined as "efforts to *prevent* or *reduce* threat, harm, loss or the associated distress" [Carver and Connor-Smith, 2010]. Stress prevention interventions involved training the employees to reduce the perceived threats, improving the work environment, preventing stress from happening from the sources, and preventing stressed employees from getting sick [Geurts and Grundemann, 1999]. Since stress is an essential ingredient of office life, we focus on the aspect of stress reduction. Knowledge workers commonly use individual coping strategies to cope with work stress [Buch and Andersen, 2013]. More recent research states that coping with stress is not just a process inside the individual, but it often "takes place in dialogue with others" [Kirkegaard and Brinkmann, 2015]. Lansisalmi et al. [Lansisalmi et al., 2000b] state two ways to cope with collective stress, which are aligned with Lazarus and Folkman's Cognitive Appraisal theory [Folkman and Lazarus, 1984]: problem-focused and emotion-focused. From their point of view, collective stress coping in the organizations is "the learned, uniform responses" from the organizational group members, who are either "trying to remove the stressor" (problem-focused), or to "alleviate the shared negative feelings it produced" (emotion-focused) [Lansisalmi et al., 2000b]. Later on, Rodríguez et al. mention two organizational-level approaches: co-active coping ("individual coping strategies shared, imitated, and replicated by the members of an organization") and collective coping ("collective behaviors organizations display to cope with the stressors to which they are exposed"). They further compare individual, co-active, and collective coping, and conclude that the collective problem-focused coping is more effective than the other two in reducing employees' stress [Rodríguez et al., 2019].

Together, stress has social characteristics, and it is socially distributed in the workplaces. For the individual employee's physiological health as well as a healthy working environment, collective stress is important enough to cope with. Previous studies in the social-psychological field found that social coping is more efficient in reducing employee's stress than coping individually. Hence, previous studies imply the need to develop group interventions to facilitate social coping with stress.

1.2 Opportunities

1.2.1 Limitations of Social-psychological Solutions

Current solutions on collective stress are mainly coming from the social psychology field. The exploration and intervention processes rely on human subjective judgment alone, which may contain confirmation bias [Forer, 1949, Nickerson, 1998, Klayman, 1995, Meyer, 2003] in recognizing the delicate changes in the environment. Biased reflection would lead to overacted worries (e.g., unnecessary coping in no-stress situations) or overlooked stressed episodes (e.g., stress would accumulate and turn into chronic stress). Therefore, we propose to explore whether technology can be leveraged to facilitate people catching more nuances of change, to balance the subjective bias, and to improve our understandings of collective stress.

The socially distributed stress and the emotional climate change dynamically over time and are hard to catch for the employees [Maeda et al., 2016]. It is a challenging and attention-demanding process to be aware of the stress and cope with it. This process needs specific training to achieve (e.g., meditation, self-regulation). Therefore, stress management is hardly applied in office workers' busy working routines. In organizations, the social-psychological solutions often require a specific role in the team to stay aware of the emotional climate among team members. And when there is an issue, the person in that role (commonly played by a team leader) needs to take action either by removing the shared stressors (problem-focused coping), or by communicating with team members (emotional-focused coping) [Lansisalmi et al., 2000b]. The dynamic process demands perceptual and problem-solving capabilities from the one in that position. The employees who experience collective stress have less autonomy and less motivation to cope with the collective situation. They often follow the instructions and act passively on these collective issues, or they turn to solutions for themselves individually [Buch and Andersen, 2013].

Overall, it is difficult to accurately estimate the stress that people experienced without bias. The process to mediate collective stress is attention-demanding and is effortful to achieve. Therefore, we see an opportunity to leverage technology to balance the subjective bias, to design for facilitating office workers' understanding of collective stress, and to fit the interventions into their existing working context as much as possible.

1.2.2 HCI for Stress Management

Stress management is a process from recognising the stressors toward taking actions (cognitive or behavioral) to cope with them. HCI tools are developed to facilitate the stages within the process from stress acquisition to feedback given. Some of those tools go further to guide stress-release training (e.g., biofeedback training [Yu, 2018]). The transtheoretical model (TTM) [Prochaska and Velicer, 1997] explains five stages of health behavior change (precontemplation, contemplation, preparation, action, maintenance) which describes the users from not sufficiently aware of a problem to get aware, decide to change, start to change, and finally maintain the change. Aligned with the TTM model, workers in HCI develop solutions, theories and models with the help of technology, typically involving the acquisition and representation of information, to facilitate the users' understanding and behavior change process.

Related to stress management, *affective computing* that was initiated by Rosalind Picard aims at detecting the users' affective status and change their behavior based on that information [Picard, 2000]. As the human physiology reacts to stress, measuring stress-related biometrics becomes the main approach in HCI stress research. Related applications of affective computing, such as biofeedback and personal informatics (PI) systems, are commonly applied in stress management. Biofeedback is a technology-mediated mind-body technique that "brings unconscious physiological processes under conscious control" [Brown, 1977]. Beyond body awareness, accompanying training sessions (e.g., breathing regulation) are usually contained within the biofeedback process for self-regulation [Kersten-van Dijk, 2018]. Personal informatics (PI), also known as *quantified self*, is "a class of tools that help people collect personally relevant information for the purpose of self-reflection and self-monitoring" [Li et al., 2010a]. A typical Personal informatics system can be described with the stage-based model brought up by Ian Li et al. [Li et al., 2010a]: preparation, collection, integration, reflection and action. Together, HCI solutions, theories and models leverage technology as a medium and as an important intervention technique throughout the user's stress coping process, from *raised awareness*, to *reflection*, to *action and maintenance*.

HCI developed sensing techniques to acquire the physiological signals of stress, quantify the stress and "feed back" the information through various media to facilitate stress coping. With the development of these personal informatics systems, the invisible and delicate changes can be measured from biosignals when the human body undergoes stress (e.g., reduced heart rate variability, increased heart rate, increased activity of sweat glands [Kersten-van Dijk, 2018]). Beyond individual-sensing techniques, technologies for organizational-level stress sensing appear to be piecemeal. Collective sensing of stress-related biosignals has been explored but not yet widely applied for further applications in stress management [Adib et al., 2015, Ravichandran et al., 2015].

Once collected, the data can be analyzed and integrated into a form that can be reflected on through various media such as visual [Feijs and Delbressine, 2017, Huang et al., 2014, Kocielnik et al., 2013, Sanches et al., 2010, Ståhl et al., 2009], auditory [Harris et al., 2014, Yu et al., 2018a, Yokoyama et al., 2002], tactile [Yu et al., 2015a], etc. Systems designed for working groups' awareness commonly use visualizations as an expressive tool in delivering information. Visual feedback design can be embedded within office workers' existing working environment unobtrusively for promoting health and collaborations. For instance, visualization design was applied to reduce office sedentary behavior [Lin et al., 2006, Ren et al., 2018], to share emotional status with colleagues [Sundström et al., 2009], and to engage reflections on the overall emotional climate in the office [Boehner et al., 2005]. However, current collective informatics systems to facilitate stress coping are mainly designed for individual users, instead of looking into stress from a collective point of view. Social facets and interpersonal interactions are under exploration specifically in stress research in HCI.

1.2.3 Motivation: HCI for Collective Stress Coping

The above observations show that collective stress is commonly occurring in the workplaces, and it causes problems, many of which are important, yet they are unsolved. It affects individual employee's health as well as a harmonious working environment. Current solutions for workplace collective stress are mainly originating from the social psychology field. These approaches contain a subjective bias [Meyer, 2003, Rabbi and Ahmed, 2014], demand specific attention and can hardly fit in office workers' daily working routines [Briner and Reynolds, 1999]. HCI researchers provide users with actionable, data-driven self-insight to help them change their behavioral patterns for wellbeing [Kersten-van Dijk et al., 2017]. However, such technological interventions are mainly designed for individual stress management instead of a workgroup. Therefore, we see an opportunity to leverage technology to facilitate people to catch more nuances of change, to balance the subjective bias, and to improve office workers' understanding of collective stress toward coping with it.

HCI researchers often apply personal informatics (PI) and biofeedback systems for stress management. PI systems offer insights on the parameters that are hardly observable by the users themselves, such as physiological parameters, which can stimulate a user's awareness of their inner state and motivate behavior change. On the other hand, biofeedback systems collect users' biosignals and provide these data back to the users in various formats to bring the unconscious physiological process under conscious control [Brown, 1977]. PI and biofeedback systems are both aligned with the transtheoretical model of behavior change [Prochaska and Velicer, 1997], which describes the process from raising the awareness, increasing the reflection, taking the action, to sustaining the behaviors. These interventions improve users' proprioceptions via visual [Henriques et al., 2011, Feijs and Delbressine, 2017], auditory [Yu et al., 2015b, Bhandari et al., 2015], and tactile [Weffers, 2010] modalities. Since visualizations are very expressive and effective in a wide variety of communication settings, we propose to visualize the stress-related physiological signals to groups of office workers as a *social-technical* intervention.

1.3 Scope of This Thesis

1.3.1 Research Questions

In this research, we aim at investigating visualization design to understand:

How could a visualization design facilitate office workers to cope with collective stress?

The main research question is divided into three subquestions:

RQ1: How could a visualization design raise the awareness of collective stress for office workers?

This question asks: what options are available to design awareness-raising systems? What are the main components of a collective stress awareness-raising visualization? Can an aggregated visualization make office workers aware of the collective stress status? Can a physiological stress-related visualization facilitate meaningful self-awareness for office workers? What are the design implications to visualize stress to facilitate office workers' understanding of their situated stress?

RQ2: How could a visualization design facilitate the reflection on collective stress for office workers?

This question asks: can a physiological stress-related visualization design from multiple users facilitate meaningful reflection on collective stress? Can users understand the visualization? Can users gain meaningful interpretations of their situated collective stress from the visualization? Does it generate additional stress on the users? How do office workers perceive the collective stress visualization in a realistic field setting? What are the design implications to visualize collective stress to facilitate office workers' reflection on collective stress?

RQ3: How could designers speculate on the applications of these visualizations for office stress management?

This question asks: what are the office workers' expectations on a collective stress visualization? How could a collective stress visualization impact collective stress management? What are the motivating factors and concerns for sharing stress information? To whom people would like to share? What are the implications to inform future design practice?

1.3.2 Research Approaches and Outline

An overview of the thesis structure can be seen in Figure 1.1. After this introduction (Chapter 1), we first deployed a literature study to establish our theoretical understandings (Chapter 2). We reviewed scientific works related to collective stress in the social-psychological field as well as theories and technologies developed for stress management in the HCI field in order to identify the implications and opportunities of designing social-technical solutions for collective stress coping. To contextualize our understandings about collective stress and generate input for further design explorations, we deployed a field interview to better understand the collective stressors and coping techniques among office workers in Chapter 3.

Based upon our theoretical and empirical understandings of collective stress, we narrow down our focus to design visualizations following the stages of the transtheoretical model of behavior change [Prochaska and Velicer, 1997]. We divide the following chapters into three phases: technology for raising awareness, facilitating the user's reflection, and developing the application scenarios. From Chapter 4 to Chapter 8, each chapter contains one study to investigate design interventions toward collective stress coping by steps.

In Chapter 4, we propose a Wizard-of-Oz intervention called "ClockViz", which is an augmented reality installation overlaid with static or dynamic pro-

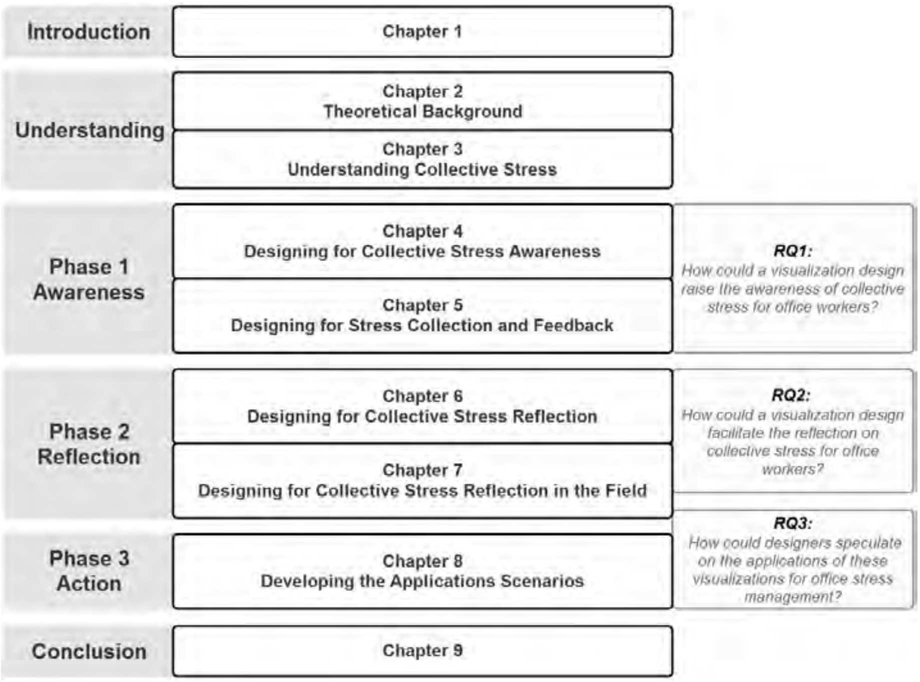


Figure 1.1: The structure of this thesis.

jection to visualize different collective stress statuses on a clock. It is meant to probe how users experience an integrated collective stress visualization. In Chapter 5, we deploy a biofeedback system called “BioFidget” that visualizes people’s physiological stress-related data through an interactive interface. These two chapters constitute our explorations on raising collective stress awareness (RQ1).

In Chapter 6, we design “AffectiveWall” as a shared display that anonymously visualizes the individual’s physiological stress-related information as a collection of stress statuses from multiple users in order to promote awareness of collective stress and enable people to make meaningful inter- and intra-personal comparisons without generating additional peer pressure. In Chapter 7, we further iterated the system of Chapter 6 with extended time for reflection to explore how it can facilitate office workers reflecting and coping with collective stress in real workplaces (RQ2).

In Chapter 8, we developed “AffectiveGarden” as a design probe for which we utilized a participatory approach called co-constructing stories to investigate how a collective stress visualization would be used in office workers’ authentic workaday routines. We discussed the implications from the rich co-constructed contextual data to inform future design practice (RQ3).

Finally, Chapter 9 concludes the thesis by summarizing the results in light of the research questions and discussing the contributions as well as the remaining challenges when designing shared informatics systems for collective stress management in a social context.

Chapter 2

Theoretical Background[1]

2.1 Introduction

In this chapter, we first derive a deeper understanding of workplace collective stress and its characteristics from the theoretical bases in the field of social psychology. We then connect related work in HCI to review current theories and technologies for stress management in order to frame the design opportunities for collective stress management. Specifically, we organize this chapter following the stages in the transtheoretical model of health behavior change [Prochaska and Velicer, 1997], framing the theoretical background from stress awareness to reflection to stress coping action.

2.2 Collective Stress and Social-psychological Coping

Collective stress is seen to be a cultural artefact [Fineman, 1995, Cox, 1991], that appears "when members of a particular organizational culture as a group perceive a certain event as stressful" [Lansisalmi et al., 2000b]. Stress is conceived to be an interaction, which takes place between an employee and his or her work environment [Caplan, 1987]. Collective stress is either caused by the

[1] Part of this chapter is included in the publication:
Xue, M., Liang, R. H., Yu, B., Funk, M., Hu, J., Feijs, L. (2019). AffectiveWall: Designing Collective Stress-Related Physiological Data Visualization for Reflection. IEEE Access, 7, 131289-131303.

poor adaptation to the working environment (e.g., risk of unemployment, group bonus, merger) or by friction inside the community (e.g., internal competition, conflicts with peers, sulky employees) [Lansisalmi et al., 2000b].

Collective stress makes people ill, destroys internal co-operation, and unbalances the working climate in an organization or working unit. For the individual, stress is associated with and contributes to anger, anxiety, and depression [Finney et al., 2013]. It breaks the balance of one's endocrine level, unbalances the autoimmune system, and contributes to cardiovascular diseases [Cohen et al., 2007, Cooper and Marshall, 1976]. All stress hurts. No matter whether it is eustress or distress, no matter where it comes from, stress is physiologically detrimental to the individual's health [Kersten-van Dijk, 2018]. For the organization, the collective stressors create gaps between peers, demotivate employees, increase the absenteeism and employee turnover rate, and deficit co-operations [Briner and Reynolds, 1999, Hassard et al., 2018]. Previous research suggests that workgroup members tend to share moods and emotions [Bartel and Saavedra, 2000, George, 1996, George and Brief, 1992]. Unfortunately, this "emotional contagion" [Pugh, 2001] applies equally to stress [Bakker et al., 2006].

In the field of social psychology, organizational-level coping with stress has two ways: co-active coping and collective coping [Rodríguez et al., 2019]. Co-active coping describes individual coping strategies shared, imitated, and replicated by other team members from the community; collective coping describes the organizational behaviors to cope with stressors that the organization is to exposed as an entity, that commonly implies a collective approach to deal with the stressors [Little et al., 2012, Rodríguez et al., 2019]. Both ways of coping are seen as a learned response that its members are trying "either to remove the stressors", or to "alleviate the shared negative feelings it produces" [Lansisalmi et al., 2000b].

However, current evaluations of collective stress commonly rely on people' subjective feelings, which contain confirmation bias [Klayman, 1995]. Overreacting on stress would exaggerate the negative effects, waste time and energy on coping with something that may not exist. On the other hand, overlooking the impacts of stress leads to the ignoring of health signals, and increases the risks of chronic diseases caused by accumulated stress [Judge et al., 2000]. Moreover, the social-psychological solutions often require "extra" time and effort to deploy these stress interventions. For example, it is challenging to organize training sessions during work because "production must go on" [Kompier et al., 2000, Nytrø et al., 2000]. Therefore, an organizational coping intervention that makes office workers realize the shared stress situation and fits in their working contexts is desired.

2.3 HCI for Stress Management

2.3.1 Behavior Change Models and Techniques in Stress Management

Personal informatics (PI) [Li et al., 2010a, Chrisinger and King, 2018] and biofeedback systems [Kudo et al., 2014, Smith, 2014] are commonly used for stress management. Personal informatics systems, also known as PI systems, are mainly designed to provide users with actionable, data-driven self-insight to help them change their behavioral pattern for the better [Kersten-van Dijk et al., 2017]. PI systems offer insights that are hardly approached by means of observation by the users, such as physiological parameters, which can stimulate a user's awareness of her/his inner state and motivate behavior change. Li et al. used a five-stage model [Li et al., 2010a], which described PI systems in five stages: *preparation*, *collection*, *integration*, *reflection*, and *action*, to help people analyze the PI systems and outcome the barriers between the stages. The model also demonstrates that, in PI systems, reflection is necessary before taking action for stress management.

A biofeedback system collects user's bio-signals (such as HRV) and provides these data back to the users in various formats in order to bring the unconscious physiological process under conscious control [Brown, 1977]. It is proven to be an efficient tool for relaxation training and stress management [Kudo et al., 2014, Reiner, 2008, Yu et al., 2018d]. Regarding stress management, HRV-based biofeedback, which is related to the users' autonomic nervous activities, is proven to be practically effective [Smith, 2014, Ratanasiripong et al., 2015, Al Osman et al., 2016] and is applied in biofeedback installations [Lewis et al., 2015, Wu et al., 2012]. Breathing-based biofeedback systems guide users to make six-per-minute slow breathing patterns that are proven to be effective in elevating HRV and mediating stress [Brown and Gerbarg, 2005, Gevirtz, 2013a]. Nonetheless, biofeedback systems are useful only if the users feel they need such kind of relaxation training, and such a need comes from a proper reflection.

PI and biofeedback systems are both aligned with the transtheoretical model of behavior change [Prochaska and Velicer, 1997]. It contains five stages: *pre-contemplation*, *contemplation*, *preparation*, *action*, *maintenance*, which describes the process from raising the awareness, increasing the reflection, taking the action, to sustaining the behaviors. The current interventions in the HCI field leverage visual, auditory, and tactile perceptions of a human being toward stress management.

2.3.2 Stress-Related Data Collection

Stress can be measured in both physiological and psychological human responses. Physiological stress can be measured when the human brain perceives the stress situation and activates the autonomic nervous system (ANS), which accelerates the heart rate (HR), stimulates the sweat glands, and increases the blood pressure (BP) accordingly [Porges, 1995, Ritvanen et al., 2006]. Researchers in the field of affective computing [Picard, 1997] highlighted several biomarkers that could potentially quantify physiological stress, including HRV, galvanic skin response (GSR) [Seo and Lee, 2010], HR, BP, etc. HRV is the most commonly used biomarker that can be measured using electrocardiography (ECG) or photoplethysmography (PPG) sensors [Zhong et al., 2005]. Decreased HRV is associated with mental stress [Sloan et al., 1994]. For short-term measurement and analysis, time domain HRV indexes (e.g., SDNN, RMSSD, AVNN, and pNN20) are more robust than frequency indexes (e.g., LF, HF, LF/HF) [Pereira et al., 2017]. Among all, the standard deviation of NN intervals (SDNN) shows a significant decrease in the stress condition [Dimitriev et al., 2008, Tharion et al., 2009, Kang et al., 2004, Van Amelsvoort et al., 2000], which can be a reliable HRV parameter for quantifying physiological stress.

Sensing physiological stress is more challenging in the collective context because the deployment of biosensors also needs to be scaled up. Contact-based wearable PPG or ECG sensors that achieve accurate timing control and exhibit a high signal/noise ratio could be a more plausible solution. A willing-to-wear and easy-to-wear smart device (e.g., smartwatch) could provide sufficient computational power and wireless connectivity to enable continuous HRV tracking, but it requires the users to wear such a device in the context. Researchers brought up contactless solutions such as VitalRadio [Adib et al., 2015], which is a room-scaled, unobtrusive solution that can track multiple users' HR and respiration simultaneously without requiring them to wear any devices. However, these solutions may not yet be precise enough for sensing HRV in daily scenarios.

Psychological (mental) stress can also be self-reported using questionnaires and scales, such as the STAI (State-Trait Anxiety Inventory) [Spielberger, 2010] and RRS (Relaxation Rating Scale) [Benson et al., 1974]. The scalability of measurement can be further improved by turning it into a mobile application.

Although it is more practical in the collective context, these personal mental stress data can only be acquired if they are voluntarily provided from the subjects (users), which results in low availability and low credibility [Bolger et al., 2003], especially in a shared context.

2.3.3 Affective Data Visualization

Stress-related data collection can be visualized to enable the users' awareness and engagement. It is considered as a type of personal visualization [Huang et al., 2015]. Ubifit [Consolvo et al., 2008] displays animated activity-related data on a mobile phone's wallpaper to improve awareness and successful engagement in physical activities. Affective Health [Sanches et al., 2010] provides the user with a real-time spiral-like data visualization of biosensor data, allowing him or her to connect these data with his or her daily activities and subjective experiences. AffectAura [McDuff et al., 2012] interactively visualizes multimodal sensor measures and predictions of the user's affective status within the contexts. Kocielnik et al. [Kocielnik et al., 2013] also visualize GSR data with a user's calendar events trying to reveal stress with their activities. Affective Diary [Ståhl et al., 2014] provides the user sensor data and daily materials (messages, photos, etc.) of past events to evoke reflection. Although some of the systems (e.g., [Sanches et al., 2010, Kocielnik et al., 2013]) visualize stress-related affective data, these are in essence personal visualizations for self-reflection.

Based on the common theory that social influences are capable of achieving higher actionability and engaging behavior change, the recent trend of self-revelation systems shifted from personal devices to applications in a social context. Miro [Boehner et al., 2003] is a system that shows an office building's collective emotional climate through an ambient dynamic painting in a public visualization for occupants to develop a sense of emotional climate, but it failed to transfer the information correctly to its audiences. FriendSense [Sundström et al., 2009] uses the 'technical probe' method to investigate the relationships and activities that constitute a group of colleagues at work. Although the expressions did not fully afford the users emotional expression, they did contribute insights into visualizing self-report data collectively in a public setting. MoodJam [Li, 2009] is an online platform where users can log in to record their mood multiple times a day and get access to look at other people's data and the history of themselves. MobiMood [Church et al., 2010] is a mobile application that allows users to share mood with friends. Since curiosity about peers' whereabouts and activities is part of human nature, a mood visualization can help users reflect upon the mood of others and potentially increase awareness. Moodlight [Snyder et al., 2015] displays the individual or a pair's arousal state using an ambient display with different colors of light. Although these systems visualize affective data in a shared context, there is no or only a weak correlation between these data visualizations and stress management.

2.3.4 Reflection on Stress

Reflection is defined by Baumer et al. as "reviewing a series of previous experiences, events, stories, etc., and putting them together in such a way as to come to a better understanding or to gain some sort of insight" [Baumer et al., 2014]. Reflection is often described as a motivation for providing increased self-knowledge for work in both health and personal informatics [Baumer et al., 2014, Branham et al., 2012, Grimes et al., 2010, Li et al., 2010b], and seen as an approach to promoting greater awareness and learning to self-manage chronic conditions [Mamykina et al., 2008], such as stress [Pennebaker and Graybeal, 2001, Sanches et al., 2010].

However, subjective confirmation biases are pervasive during self-reflection [Nickerson, 1998]. People tend to seek and interpret evidence that aligns with their existing beliefs [Klayman, 1995]. In stress management context, misinterpreting stress among individuals may account for inefficient employees and deteriorating relationships [Parkes, 1985]. Group reflection could be beneficial for people to discover a phenomenon that is sometimes difficult to observe individually or subjectively [Fleck and Fitzpatrick, 2009, Branham et al., 2012, Isaacs et al., 2013]. In this case, the individual bias can be made explicit and adjusted from multiple perspectives through conversations [Baumer et al., 2014]. Though group reflection can facilitate social sensemaking [Costa Figueiredo et al., 2017, Malu and Findlater, 2017, Mentis et al., 2017], concerns on privacy [Garbett et al., 2018], data control [Kostkova et al., 2016], workplace surveillance [Gimbert and Lapointe, 2015, Wicks et al., 2010], and the commodification of personal data [Shklovski et al., 2009] had also been noticed [Garcia and Cifor, 2019].

Reflection is a complex and nebulous concept that makes its evaluation much more difficult [Baumer et al., 2014, Sumsion and Fleet, 1996]. In reflective practice research, levels of reflection are brought up: description, reflective description, dialogic reflection, transformative reflection (from low to high) [Fleck and Fitzpatrick, 2010, Hummels and Frens, 2009]. Questionnaires for self-reported reflection are also widely applied in reflective practice [Priddis and Rogers, 2018]. For the work in health and personal informatics, reflection plays a prominent role to *raise awareness*, *foster insight*, *increase self-control* and *promote behaviors* [Baumer et al., 2014]. McGuire's information processing theory claims five requirements for a message to eventually achieve action: *exposure*, *attention*, *comprehension*, *yielding*, and *retention*. Reflection is constantly constructed during this process. Previous reflective informatics experiences suggest to combine qualitative data with quantification to help understanding the complexity of reflection [Baumer, 2015]. And group reflection opens up new possibilities to evaluate reflection itself through a more natural-setting conversation in a social context [Baumer et al., 2014].

2.3.5 Action Stage in Stress Management

The self-improvement hypothesis of PI assumes two steps: "self-tracking leads to insight", and "insight leads to behavior change" [Kersten-van Dijk et al., 2017]. Nevertheless, the well-supported insight is unlikely to translate to behavior change directly [Li et al., 2010a]. A variety of transtheoretical models explain a similar pattern toward behavior change: users may *not be sufficiently aware* of some problem at the beginning; then some awareness occurs by the appearance of an intervention that makes them *aware of the problem*; to some extent it stimulates them to *have the intention to change their behavior* and *make actual changes*; preferably the intervention can facilitate their behavior *maintenance* to keep the new behavior [Kersten-van Dijk et al., 2017]. The stage-based model of PI reveals the potential barriers between stages that may lead to users dropping out of this process [Li et al., 2010a]. A lived informatics model of PI also indicates a lapsing stage that happens when users stop actively using a self-tracking tool because of forgetting, upkeep, skipping, and suspending [Epstein et al., 2015].

Researchers provide abundant insights in motivational strategies to overcome these barriers and lapses. Persuasive technology [Fogg, 2002] summarizes factors to motivate behavior change. As one of the qualities in persuasive systems design [Oinas-Kukkonen and Harjumaa, 2009], social support can empower behavior change through recognition, comparison, social facilitation, competition, corporation and so on. For example, Fish'n'Steps utilizes animated fish metaphors to visualize multiple users' daily physical activities on a public display, which improves users' attitudes and reinforces fitness behaviors through engaging them interact with the virtual pet character and communicate with peers [Lin et al., 2006]. In a stress management context, PI and biofeedback systems often provide users with actionable, stress-related insights to change their behaviors for their wellbeing. Unlike PI systems, biofeedback systems often contain a specific training session that helps users learn to deliberately get control over their physiological process [Kersten-van Dijk, 2018]. To facilitate stress regulation, breathing-based biofeedback systems guide users to make six-per-minute slow breathing patterns, that are proven to be effective in mitigating user's physiological stress [Gevirtz, 2013a, Brown and Gerbarg, 2005].

2.4 Conclusion

In this chapter, we first introduced definitions, effects, coping techniques and remaining challenges of collective stress from a social-psychological point of view. Then, we reviewed current literature in the HCI field to facilitate stress coping from the perspectives of the behavior change stages: stress-related data collection, affective data visualization, reflection on stress, and action stage in stress management. Overall, we gained the following insights: 1) the intrinsic need to manage collective stress for the individual's health as well as the collective working climate; 2) the limitations of current social-psychological solutions by using subjective estimation; 3) the established and effective HCI techniques in stress management; and 4) the potential of leveraging PI and biofeedback systems for collective stress coping. These insights can be used as the theoretical foundation to apply HCI techniques in collective stress coping. In the next chapter, we present an initial understanding of collective stressors to get to know the use context of workplace scenarios.

Chapter 3

Understanding Collective Stress: A Field Interview[1]

In the previous chapter we have established an understanding of collective stress in the workplace and affective-related informatics systems for group awareness in current HCI research. We realized the characteristics of collective stress and we identified opportunities of developing social-technical interventions following the behavior change process toward collective stress coping. In this chapter, we conduct a field interview in order to contextualize our understandings about collective stress in a specific organization, and generate input for future design explorations.

3.1 Introduction

Stress commonly exists in the workplace scenarios, it is a cultural phenomenon that distributed socially [Kirkegaard and Brinkmann, 2016]. Excessive stress affects office worker's health [Cohen et al., 2007] as well as interpersonal relations [Porter, 1996] [Lansisalmi et al., 2000b], so the management of stress is crucial. Collective stress occurs when members of a particular organization perceive certain events as stressful [Lansisalmi et al., 2000b]. To design inter-

[1] Part of this chapter is included in the publication:
Xue, M., Liang, R. H., Yu, B., Funk, M., Hu, J., Feijs, L. (2019). AffectiveWall: Designing Collective Stress-Related Physiological Data Visualization for Reflection. IEEE Access, 7, 131289-131303.

ventions for coping with collective stress, a sufficient understanding of the collective stress context in a real working organization is essential. We conduct a field interview within a specific organization with young researchers to contextualize our understandings on where the stress is coming from and how office workers reflect and cope with their stress in their organizational context. We expect that the results can uncover office workers' lived experiences on stress as well as their coping strategies with stress in an organizational context. Based on the findings, a set of design opportunities will be generalized for designing collective stress coping interventions.

3.2 Method

An exploratory semi-structured interview was conducted to better understand how the office workers from a specific organization reflect on stress and cope with stress in their workplace. Participants in the interview were 25 Ph.D. employees [Levecque et al., 2017], all working in a research-related job in a university with various expertise in design, engineering, and architecture. This target user group was selected because Ph.D. organization experiences psychological distress. And the prevalence of mental health problems is higher than the general highly educated population [Levecque et al., 2017]. The similarity of job characteristics made them share similar experiences of stress [Dewa et al., 2011]. In order to avoid that gender and cultural differences might affect the results of the experiment, the sample involved 13 females and 12 males, and the nationality ranged from nine countries including Asia, Europe, North America, and South America. Facing the fact that doctoral researchers have to cope with different stressors in different phases of their research, we took the participants from three groups based on the three phases: exploration phase, execution phase, and writing phase. All samplings are evenly taken from these three phases.

The interview aimed to explore the main factors that elicited stress during their daily research life and how they cope with the stress. A semi-structured questionnaire was designed to evoke participants' recall of their stressed moments and the factors associated with them. For instance, questions like *"Please describe a stressful moment of your research life"*; *"Where do you think your stress comes from?"*, and *"How do you cope with stress in everyday life?"* were asked and the answers were recorded during each interview. The preference of their stress management techniques in daily life was also asked for at the end of each interview.

In total, 458-minutes interview data from the 25 in-depth interviews were recorded and transcribed by the first author into text. Afterward, the transcriptions were analyzed using Dedoose[2], a qualitative and mixed methods analysis platform. To make sure the results were objective, two people were invited to encode the data independently using Dedoose. Then the two coders presented their coding results to each other and made a tree diagram to categorize the main factors of the results together.

3.3 Results

3.3.1 Individual and Social Stressors in the Workplaces

Individual Stressors	**#**	**Social Stressors**	**#**
Multitasking	25	Contagion	21
Procrastination	22	Bad communication	16
Uncertainty	19	Comparison	8
Deadline	17	Judgement	6
Unmet expectation	16	Disagreement	3
Time management	13	Loneliness	3
Task management	12		
Distraction	12		
Perfectionism	10		
Ideality and reality	5		
Input and output	4		
Financial pressure	4		
Low productivity	3		

Table 3.1: Individual and social stressors according to the frequency of mention (#: Head Count)

Table 3.1 shows workplace stressors that were classified into two categories, *individual* stressors and *social* stressors. All the mentioned stressors were ranked by the head counts. The top three mentions are: multitasking (100%), procrastination (88%), and contagion (84%). The detailed descriptions of stressor categories and example quotes for *Individual* stressors and *social* stressors can be found in Table 3.2 and Table 3.3.

[2] https://www.dedoose.com/

Individual Stressors	#	Description	Example Quotes
Multitasking	36	Stress comes from the performance of more than one task at the same time.	*"But special is if I had deadlines, building prototypes, then painting, gluing, I don't know, whatever, electronics, everything together. So, yeah. The quality of my work suffers obviously from it." (P9)*
Procrastination	52	Stress comes from delaying or postponing a task or set of tasks.	*"So I can have some fun in 2 hours, then I'll do a bit more during the night. Then it's 5 o'clock and I'm tired then. . . That's annoying." (P17)*
Uncertainty	20	Stress comes from being uncertain.	*"Designers are more creative and they don't see the end before you start. While for engineers we have to see the end before we get started. That's also sometimes become a problem. Everything is planned and organized but as a designer, you cannot plan too far." (P8)*
Deadline	43	Stress comes from accomplishing a task within a narrow field of time.	*"Deadline gives me efficiency, but also stress." (P4); "the stress is that we are trying to meet up the deadlines that we have set." (P8)*
Unmet expectation	43	Stress comes from not achieved an expected results.	*"Panic! The results of the experiments are not as good as I expected." (P2)*
Time management	26	Stress comes from organizing and planning how to divide time.	*"So I spent half time here and half time there. In principle the program is 3 years so I have to do it faster." (P5)*
Task management	18	Stress comes from handling tasks to ensure projects get completed on time.	*"People are still able to interact with me, but still you have to be careful to the cameras, be careful to the physiological data, sensors, if it was attached, then easy everything, going properly, and then you have to take care also the facility also the caregivers given in the nursing home. Then everything is a lot of stress." (P10)*
Distraction	10	Stress comes from things that prevents someone from concentrating.	*"The problem that I sometimes want to finish something, then I get all these emails, and if I don't really want to do this one task, I easily distracted by the other things. So at some point you just the whole day doing all these small tasks, well actually you'll stressed out about this one thing." (P17)*
Perfectionism	18	Stress comes from the need from achieving perfection.	*"I just want to do everything perfectly. I'm a person that really wants to do everything really neat, so that sometimes create stress while I'm doing. I am definitely a perfectionist." (P20)*

Table 3.2: Categorization of individual stressors (#: Number of Times Mentioned)

Social Stressors	#	Description	Example Quotes
Contagion	32	Stress comes from the spreading of stressful feelings from others.	*"They panic all the time. I might have bad feeling affected by them." (P6); "I think when you see people who are very stressful, I wouldn't know how it's gonna affect me but it will certainly change the mood in the room" (P5)*
Bad communication	52	Stress comes from the discrepancy between what is said and what is heard.	*"Sometimes they start to ask questions on my 'blank moment' then I don't get the whole question and get panic." (P6)*
Comparison	16	Stress comes from comparing with other people.	*"And from the second year, they are usually starting to do the work. But for me, I have to not only do all of that, create the experiment, run the experiment, iterate it, do the analysis and write a report by August." (P23)*
Judgement	7	Stress comes from others' unpleasant comments.	*"My promoter never say I was doing perfectly." (P10)*
Disagreement	5	Stress comes from the lack of approval.	*"When I had to basically pitch my idea of the project or to the direction I want to go into. Because that was the point where I was fearful of people stopping me. Cause I have this plan 'we can do this and that and that that that..' and then that they say 'NO, do something else'...if you do not approve, I'm gonna be really really screwed." (P14)*
Loneliness	7	Stress comes from the perceived isolation.	*"I was the only PhD student in the lab, I don't have anyone to talk to." (P10)*

Table 3.3: Categorization of social stressors (#: Number of Times Mentioned)

Multitasking and *procrastination* belong to *individual* stressors that describe the stress coming from an individual performing more than one tasks at the same time and postponing a set of tasks, respectively. People get stressed from handling multiple tasks and switching between tasks aligned with findings in Gloria Mark's research [Mark et al., 2014]. This phenomenon reflects the busy working routines with various types of ongoing tasks is common among office workers. Procrastination is another top-mentioned individual stressor that usually exists in Ph.D. researchers. For example, *"I know the fifth day I didn't do anything. And the rest of the days I feel a sort of guilt. I'm not working and basically doing nothing" (P24)*. They delay or postpone tasks because they *"don't have the drive or pressure" (P14)* to handle the task. It didn't solve any problem but make people *"feel the pressure when it's time to deliver the work" (P13)*. The procrastination is also a recurring theme in the PhD Comics[3]. See Figure 3.1.

Figure 3.1: "Piled Higher and Deeper" by Jorge Cham. www.phdcomics.com.

Contagion is a *social* stressor that describes the stress coming from the spreading stressful feelings from others. They described that they could notice others' stress according to their personalities. People have their own ways to express their stress, some are close up and not approachable, *"they stay in that corner...doesn't want to talk about it"*; some are *"show it out in an annoying way or aggressive way"*. And participants expressed their helpless to intervene this situation. For example, when someone doesn't want to talk about it, *"you feel more helpless. I want to help you but I can't really because you close off"*. When

[3]http://phdcomics.com/

they get influenced by colleagues who act it out, like P14 mentioned, he knows when his colleague is stressed because his colleague starts whistling, *"that's really bad whistling, I was like 'come on, dude'..."*. Other *social* stressors also received considerable mentions, like bad communications (64%) and peer comparison (32%).

3.3.2 Reflection Contains Subjective Confirmation Bias

Our findings confirmed subjective confirmation bias exist among our participants when they reflect on others' stress and the office atmosphere, because they are trying to interpret the stress from their subjective speculations in a way that supports their beliefs (confirmation bias [Nickerson, 1998]). Participants speculated the overall working atmosphere by their subjective feelings alone, for example, *"a big part of the environment is not that stressed"*. Participants make conclusions about others' stress by their stereotypes unconsciously, for example, they assume researchers in their last phases of research would be more stressful than others, *"I think about my colleagues who are in the same program. They tend to be more stressed because they're going to write their thesis"*. And they also make conclusions about others' stress status by themselves, like *"Sometimes the girl in the room is very stressed..."*. They speculate the reasons, *"I would think, OK, what's going on"*, and make sense of the situation from a subjective point of view, *"it's probably her problem"*. Participants also believe others' stress would contribute to the overall emotional climate of their workplaces, for instance, *"...if they are in my office, that would definitely change the mood of it"*. And some feel stressed about others' attitudes on their performance, such as *"He probably thinks I'm such a stupid student"*. In fact, these speculations on others and the overall stress are impossible to be made objectively.

Biased perceptions on stress would bring unnecessary worries, overlooked health problems, and prevent people from coping with stress efficiently. Overreacting on stress would bring unnecessary anxieties, like P23 mentioned, *"I think stress is not something that one can control always. And if you are constantly thinking about something and this stresses me out, it can affect how you behave or interact with other people"*. Neglecting stress was often happening when people got occupied by their workload, *"It influenced, or I might be preoccupied with my work then therefore not show that much attention or interests, to others as well..."*. Ignoring stress may lead to prolonged stress that affects mental and physical health. Sometimes people were aware of the stress and sedentary behavior during work. However, they also realized the difficulties in stopping and making changes. For instance, participant 9 indicated *"I had so many deadlines,* *and after I finish the deadlines, and then I was ill for 3 days. Then I knew okay, this was too much, I have to change something to prevent this next time. It's not because of the deadlines, it's cool. It's just when do you think something is finished. There's always that 'extra hour' that 'extra thing' you can do. At a certain point you have to decide for yourself 'okay, enough is enough'. I did my best more than I can do. That's something I really had to learn. Not to try to do 'a little bit extra' just because I had the time. It doesn't always increase the end results, and the quality of results".*

3.3.3 Individual and Social Coping Strategies in Use

	#	Coping Strategies	Example Quotes
Individual Coping	14	Taking a break (11); Doing something after work (9)	*"after the meeting we gonna be 'free'. We just need a break. Just reward myself." (P8); "I go to the gym." (P13)*
Social Coping	14	Discussing with colleagues (12); Going to a psychologist (2); Talking to family (2); Talking to friends (1)	*"we met quite frequently...to discuss common issues, and actually we try to study together and write a paper together, and actually we did." (P7); "I was with a mental psychologist every week to talk about that stress because I couldn't handle it." (P25); "My husband is awesome, he always supports me when I get stressed. I complaining to him a lot." (P23); "...meet with friends is relaxing." (P11)*

Table 3.4: Individual and social coping strategies (#: Head Count)

We collect how the young researchers cope with their stress in their daily life. We summarize the coping strategies and categorize them into individual coping techniques and social coping techniques in Table 3.4. Individual coping includes: taking a break, for example, distracting oneself (P1, P3, P5, P7, P8, P11, P17), listening to music (P9, P23), and praying (P4, P13). Some participants mentioned they would do something after work, like watching TV (P1, P2, P7, P9, P17), going to the gym (P13, P16, P17, P21), sleeping (P1, P17), drawing (P2), reading (P9), cleaning (P16), cooking (P17), and shopping (P4). Interestingly, the results showed that participants use social coping strategies as commonly as they use individual coping strategies. Each category has 14 people utilized in their daily life. Social coping describes how the individual user mediates his or her stress through interacting with others. For example, discussing with colleagues (P1, P2, P4, P5, P7, P8, P9, P10, P11, P13, P19, P22), going to a psychologist (P10, p25), talking to family members (P13, P25), and talking to friends (P12).

3.4 Discussion, Limitations and Conclusion

According to the results, we contextualize our understandings of the workplace stressors, confirmed the unavoidable subjective confirmation bias within the social stressors reflection process, and identified the coping strategies that one mostly applied by young researchers in their daily contexts. We generalize these into three design guidelines from the empirical results to inform future design in facilitating stress coping interventions within working organizations.

Bring awareness of collective stress to mediate office workers' confirmation bias in reflecting on social stressors. Our findings showed the subjective confirmation bias when office workers were speculating their colleagues and the overall working climate. To mediate the biased interpretations on social stressors, designers can strengthen the mutual understandings among office workers. For example, we can design awareness systems to bring people the social stress status through collecting and offering the stress information to the organizations. Previous social awareness systems and shared systems provide us abundant examples how to bring awareness to multiple stakeholders [Niemantsverdriet et al., 2019, Baumer et al., 2012, Boehner et al., 2005].

Avoid attention-grabbing from burdening office workers' already-busy routines. Our findings identified that one of the common stressors as perceived by office workers is multitasking. It indicated their busy working routines filled with handling and switching between multiple ongoing tasks. Therefore, the stress-coping intervention design should avoid adding to their already-busy tasks. The design should ambiently fit into the current office scenarios, and the interaction should avoid grabbing too much attention from office workers. Peripheral interaction [Bakker et al., 2015] and ambient display [Vogel and Balakrishnan, 2004] can be applied to fit in office workers' existing routines.

Consider social facets and engage communications in stress intervention design. As can be seen in our findings, social stressors are common in office workers' daily working routines, and communication is one of the major strategies for stress coping. Since office workers use to complaining and discussing their troubles with each other to mediate their stress, design can trigger and facilitate interpersonal communication. Communications can be triggered in design cues within a preferable context (e.g., with the right audiences that users would like to open up with, and at the right time without too much interrupting the work). Previous research makes decisions on the timing of stress intervention through contextual and temporal visualizations [Sharmin et al., 2015]. Their findings enlighten the design of just-in-time adaptive stress interventions. Multi-model data can also be leveraged to predict better stress intervention delivery timing [Sano et al., 2017] in future design.

A collection of 25 participants is a very small sample, and the young researchers' organization is very limited in representing the total population of office workers. However, through this pilot interview, we are able to contextualize our initial understandings of collective stressors in an organization. And we identify ways that can inform future design in developing collective stress interventions.

In this chapter, we conducted a field interview to contextualize our understandings about the workplace stressors. The results identified the major individual and social stressors that commonly exist in the workplaces. The individual stressors revealed office workers' busy working routines in handling and switching between various types of ongoing tasks. And the social stressors reflect the interpersonal interactions in stress creation, which implied the necessity to address these social aspects in future stress management intervention design. The results also indicated that subjective confirmation bias is common when people speculate on others' stress, which would bring unnecessary worries, potential health problems, and prevent people from coping with stress efficiently. We also spotted office workers used to cope with stress through communications, which can be facilitated by design. We ended this chapter by proposing three design opportunities for developing stress coping interventions from a collective point of view. This work gives us input for our design explorations in the next step.

Chapter 4

Designing for Collective Stress Awareness[1]

In the previous chapter, we identified the workplace stressors and generated three design opportunities to enlighten the design of stress coping interventions. Based on the contextualized understandings established in the previous chapter, in this chapter, we design visualization as an intervention for raising the awareness of collective stress for office workers. We design ClockViz, an augmented reality installation overlaid with static or dynamic projection to visualize three different circumstances of collective stress on a clock. The installation expresses three different collective stress extensions: everyone feels stressed; some feel stressed while others do not; no one feels stressed. We conduct a Wizard-of-Oz study to understand how people experience the two visualizations under different collective stress circumstances, and generate potential solutions to collective stress sensing for designers to apply into their interactive design intervention.

[1]This chapter is based on the publication:
Xue, M., Liang, R. H., Hu, J., Feijs, L. (2017). ClockViz: Designing public visualization for coping with collective stress in teamwork. In Proceedings of the Conference on Design and Semantics of Form and Movement-Sense and Sensitivity, DeSForM 2017. IntechOpen.

4.1 Introduction

People often experience stress in the workplace. From our previous exploration in Chapter 3, we found that stress normally comes from individual stressors such as multitasking, next to social stressors such as contagion. The impact of stress can be either positive or negative. Thus, stress can be categorized into eustress and distress [Fevre et al., 2003], respectively. Eustress normally gives people motivation to deal with challenging routines, produces higher performance, and generates positive feelings, which can give people a sense of achievement during work. However, researchers also have found some evidence that stress can lead to illnesses emotionally and physiologically. Overloaded prolonged stress leads to illnesses like anxiety, depression, anger, headache, insomnia, indigestion, or even worse. It lessens people's resistance to diseases [McEwen, 2004]. Helping people to adapt to the changing levels of stress is a significant challenge for interaction designers to promote healthier working and lifestyles.

Several techniques can be used as tools for designing applications of stress management. Sharma et al. demonstrated some common techniques that include analyzing physical signals such as eye gaze, pupil diameter, voice characteristic, and face movement and physiological signals such as electroencephalography (EEG), blood volume pressure (BVP), heart rate variability (HRV), galvanic skin response (GSR), electromyography (EMG), etc. [Sharma and Gedeon, 2012]. With these input signals, the information can be further visualized as several forms of biofeedback [Ibarissene et al., 2014] to raise the awareness and therefore help the users deal with the stress. However, these physiological measuring methods seem to be hardly scalable because the deployment cost is directly proportional to the number subjects wearing the devices. Due to the limited scalability of measurements, the designs of biofeedback mechanisms are limited to stress management for individuals, instead of collective and organizational stress.

In this work, we aim to explore the visual biofeedback design of collective stress and to treat a group of people as an entity. Collective stress, as a certain type of stress, represents the stressful feelings of members in a particular organization [Lansisalmi et al., 2000b]. Like individual stress, collective stress could be caused by external stressors such as natural catastrophes, economic crises, and political collapses. Moreover, collective stress may also be affected by some internal stressors like conflict or propagation between individuals. It could lead to less productivity, poor performance, strained relationships, or members' burnout. Providing suitable visual biofeedback design of collective stress helping the workers dealing with the stress may increase their performance and lead to healthier ways of teamworking.

Therefore, we develop ClockViz (Figure 4.1), a projection-mapped clock to evaluate the concept. ClockViz visualizes collective stress information by visually augmenting a clock that is a public display in the working space, so workers in situ can easily perceive the collective stress information visually when they are working together. For reasons of simplicity, we design a static (Figure 4.1b) and a dynamic (Figure 4.1c) projection as overlays to visualize three different statuses of collective stress on a clock as an augmented reality installation. Initial user feedbacks are gathered from a pilot testing to understand the effectiveness of the provided visualization under a pressure cooker. We discuss future research directions and suggestions for designing for collective stress awareness.

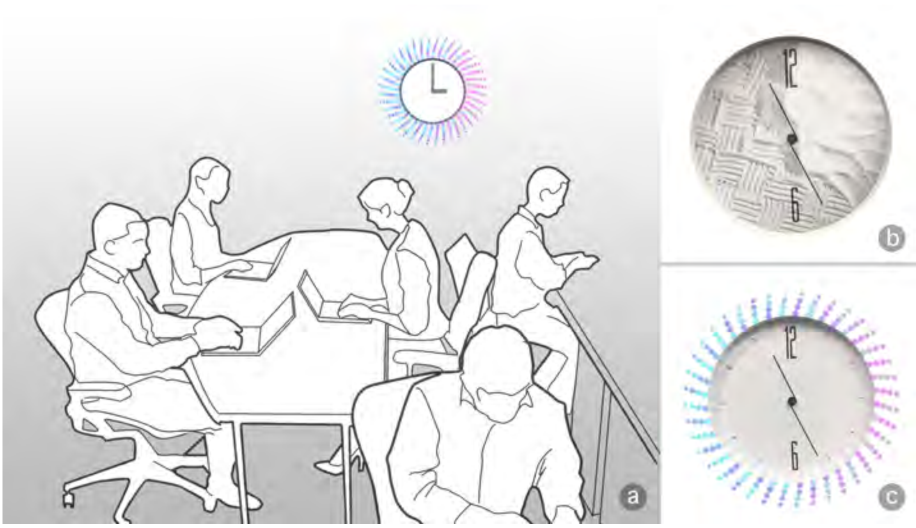


Figure 4.1: ClockViz. (a) Illustration of the application scenario. (b) static visualization. (c) dynamic visualization.

4.2 Related Work

Individual stress coping strategies had been framed in the domain of interaction design. These designs [Van Rooij et al., 2016, Henriques et al., 2011, Bhandari et al., 2015] mostly correlated to other domains, such as stress measurement and social science. Hence, this section will explain stress-related work in the following three sections: social factors of stress management, stress measurement methods, and biofeedback for visual perception.

4.2.1 Social Factors of Stress Management

In the perception of social science, many factors can cause stress in the context of a collective, for instance, the changing of organizational structure, leadership style, and quality; the demands of tasks and roles; the communication within an organization; and so on [Manning and Preston, 2003]. A majority of the previous studies on collective stress coping methods are about sociological interventions like training, rewarding, and self-developing [Manning and Preston, 2003]. Sociological interventions have also been explored extensively in catastrophic psychology [Pennebaker and Harber, 1993]. However, stress management intervention is seldomly approached in empirical stress research in the context of organizations [Stellman, 1998].

4.2.2 Stress Measurement Methods

Other than physical and physiological techniques noted above, stress can also be measured through scales or questionnaires. Known methodologies to measure stress include STAI [Spielberger, 2010], RRS [Benson et al., 1974], PANAS scale [Watson et al., 1988], perceived stress scale [Cohen et al., 1983], and Hassles scale [Dohrenwend and Shrout, 1985]. The poor scalability of these methods narrows down the interactive design solutions. Gloria Mark et al. use multi-methods that include heart rate monitors, computer logging, daily survey, general questionnaire, and interviews to measure college students' stress. She proposed that the amount of multitasking is positively associated with stress [Mark et al., 2014]. This research is one step further toward helping people change their behavior to reduce stress. In this case, collective stress information can be objectively measured, which provides future researchers a way to gain collective data. Unfortunately, no possible solutions to collective stress were brought up at the end. Moreover, stress status can be created and adjusted by asking the users to complete difficult tasks or challenging games, such as memory card game [Quesada et al., 2012], domino game [Admon et al., 2013], soccer game [Kempes et al., 2008], and first-person shooter game [Bouchard et al., 2012], for which validity and practical applicability have been proven in previous research [Haneishi et al., 2007].

4.2.3 Biofeedback for Visual Perception

The combination of stress measurement and interaction design has been well explored. Some artifacts had been designed to give biofeedback of individual's stress status and to visualize personal biological parameters [Van Rooij et al., 2016, Henriques et al., 2011], or do interventions [Yu et al., 2015b, Bhandari et al., 2015, Gaggioli et al., 2014] to mediate their stress through various methodologies. For instance, Van Rooij et al. [Van Rooij et al., 2016] applied RSP data in their work, and Henriques et al. [Henriques et al., 2011] offered BVP parameters. Beyond the visualization level, Yu et al. designed an auditory display providing HRV to help biofeedback training [Yu et al., 2015b]. Bhandari et al. [Bhandari et al., 2015] also applied a music biofeedback intervention to help users regulate their stress. Gaggioli et al. verified that the interreality protocol, which links the virtual and the real world through experiential virtual scenarios, yields better outcomes to facilitate psychological stress coping than the traditional stress treatment [Gaggioli et al., 2014]. Some of these studies involved solutions considering visual, auditory, and tactile perceptions of a human being. Since visual perception causes less interruption and disturbance, it has been widely applied in biofeedback visualization. Thus, we will mainly discuss biofeedback for visual perception in this case. Various patterns or physical objects associated with natural patterns had been used in former studies [Ibarissene et al., 2014, Matthews et al., 2015]. A 3D graphic serious game design on a smartphone provides cardiac biofeedback and adjusts user's breath through animation in order to help people relax through acknowledging their biomedical signals in combination with certain training exercises [Ibarissene et al., 2014]. MoodLight [Matthews et al., 2015] is a real-time interactive lighting system, which is designed to explore personal and social implications of users' arousal data. Matthew et al.'s research provides understandings on how the biosensor data representations influence individual user's perceptions in the context with a friend. Those studies verified that present biometric information to individuals could provide a sense of control and possibly regulate themselves on their own in specific scenarios.

4.2.4 Summary

Our review shows that the discipline of interaction research and design has taken a great interest in stress-related topics in recent years. The topic of design artifacts to mitigate individual stress appears to be well-explored. Nonetheless, researchers mostly use technical solutions for stress measurements on individual users instead of a group of users as an entity. Interaction designers design artifacts to deal with social issues and neglect collective stress because of practical limitations. Hence, this research focuses on seeking practical solutions for collective stress management in teamwork.

4.3 Design

4.3.1 Design Considerations

According to the related work, we assume that biofeedback visualization information of collective stress could help the team members more aware of their stress. The visualization should be "a tool that brings people together to address issues instead of isolates people as individuals" [Le Dantec, 2016], based on the practical theory of social design. Thus, providing a public display is more preferable than using personal displays of individual users. Our research question is: could public biofeedback visualization raise the collective stress awareness and have meaningful influences on participants during teamwork?

In the context of designing visualization of public display, three main considerations while forming the visualization design are the choice of expression, the mapping from collective stress status to corresponding expression, and the avoidance of interruption or distraction.

On the choice of expression, we try to change the environment as least as possible but provide a display so that the workers can recognize their daily behaviors in the display we provide to them. By observing common working scenarios, we found out that many public working spaces have a clock on the wall, which is a public display of time, allowing us to design a nonintrusive installation by augmenting a clock. Regarding a clock as a display of time, time-related collective pressures are suitable to be displayed on it. To further explore the possible mapping from collective stress status to corresponding expression, we utilize the interview results from the study in Chapter 3, and summarize three common collective stress statuses in the teamwork with time:

Everyone in the team feels stressed. Before a deadline, everyone feels stressed from the time pressure. When the deadline is approaching, everyone is doing challenging tasks on their own. The team that suffers from a certain amount of stress among all team members often has a stressful working atmosphere. In this case, the collective stress steadily changes with time.

Someone(s) feel stressed, someone(s) do not. This happens when there are dependencies between the divisions of labor (e.g., one has to wait for another one's response) and unbalanced divisions of labor (e.g., someone's task is beyond his or her capability, but someone else's task is not or even easy). The uneven stress would lead to an unharmonious working atmosphere and cause friction between team members (e.g., members argue or blame each other). So, the collective stress unsteadily changes with time.

Everyone in the team does not feel stressed. This happens when the deadline passes, and the next deadline is still far away, and no one in the team suffers from time pressure. In this case, the stress condition is affected by the individual factors, and the collective stress visualization does not seem to be necessary.

To avoid interruption or distraction, the clock should stay ambient in the background, and the coworkers should notice the visualization only when they look at the clock to check the time. Therefore, the visualization should avoid attention grabbers that may interfere with the user's peripheral perception, such as salient movement, startling changes of colors or intensities. Therefore, the visual augmentation should be designed either as static as possible or consists of slow dynamic movements.

4.3.2 Designing Ambient Visualization of Collective Stress

Based on the principle outlined in Section 4.3.1, we propose two proof-of-concept visualizations of collective stress: static and dynamic. Each expression contains the three collective stress statuses that we discussed previously: (S0) no one in the team feels stressed; (S1) everyone in the team feels stressed; and (S2) some feel stressed, some do not.

The static visualization (Figure 4.2) is an ambient intervention, which is inspired by a Zen garden. The sand traces change imperceptibly slowly within a glance, so it appears to be static. When everyone in the team feels stressed (Figure 4.2a), the entire clock is covered by dense patterns, showing the even pressure of every team member. When some feel stressed, but others don't (Figure 4.2b), the sand traces appear to be bipolar: half of the clock is covered by dense traces, but half of it is not. The ratio of the two parts also displays the uneven loadings of workers. When everyone in the team does not feel stressed (Figure 4.2c), the sand traces are slowly erased, so it appears to be peaceful. With these trace patterns of the sand, the design also attempts to evoke inner peace, calmness, and tranquility of people.

The dynamic visualization (Figure 4.3) inspired by water shows. The light pattern spins, dilates, and erodes in a stable speed, which is governed by several sine functions, to provide a dynamic but peaceful representation when the users take a glance at the clock. When everyone in the team feels stressed

Figure 4.2: Static visualization. (a) Everyone in the team feels stressed. (b) Some feel stressed, some do not. (c) No one in the team feels stressed.

Figure 4.3: Dynamic visualization. (a) Everyone in the team feels stressed. (b) Some feel stressed, some do not. (c) No one in the team feels stressed.

(Figure 4.3a), a colorful spiral is displayed around the clock with dense, long traces, showing the even pressure of every team member. The length of the trace changes with the time pressure. When some feel stressed, but others don't (Figure 4.3b), the density of the spiral varies with time to display the uneven loadings of workers. The density of the spiral also changes according to the unevenness of task loads. When nobody in the team feels stressed (Figure 4.3c), the length of the trace is reduced, so it appears like a peaceful, rotating color wheel. The design also attempts to use many positive metaphors such as the colors and shapes [Lakoff and Johnson, 1980] to provide cheerful experiences.

4.4 Pilot Study

To understand the effectiveness of our design, a pilot study was conducted to understand the users' behaviors and responses to the provided visualization in teamwork under time pressure.

4.4.1 Participant and Apparatus

Sixteen participants (seven males, nine females) were recruited and divided into two groups: eight for the static visualization and another eight for the dynamic visualization. For each visualization, the eight participants were further evenly divided into two teams. The study is conducted in a meeting room where a projection-mapped clock was installed on the wall. As shown in Figure 4.4, the visualization of the projection is controlled by a hidden computer.

Figure 4.4: Experimental apparatus.

4.4.2 Tasks and Stimuli

A domino game is chosen as a pressure cooker because of the following three reasons. First, domino is a game that participants from various cultural backgrounds are familiar with, introducing an immediate walk-up-and-use system to our study. Second, domino games not only require but also encourage teamwork. Third, the difficulty of domino games is easily adjustable based on the complexity of construction. By assigning different domino challenges to a team by asking them to complete it within a given period, we can test our system and obtain initial feedback with this pressure cooker.

Each team was asked to finish each of the three tasks in 5 minutes. The tasks are designed in different difficulty levels. The first task is to collaborate with each other and make a 2D pattern that can be knocked down in one push. This refers to an easy task that is associated with the low-stress status. The second task is to collaborate with each other and make a 3D round tower, as shown in Figure 4.4. This refers to a relatively stressful task for everyone in the team. In the third task, we divide the team into two groups: one group is asked to build a 3D tower, and another group is asked to build a 2D pattern in the middle of the 3D tower. This refers to two uneven and mutually-dependent stressful tasks performed by each of the two groups in the team.

The transitions of the visualization are human-controlled. The stress visualization of all the tasks started from the stressless visualization (S0). In Task 1, we keep the same visualization until the end. In Task 2, we switch the visualization from S0 to the even stress visualization (S1), 1–1.5 minutes after the task starts without noticing the participants. Similarly, in Task 3, the visualization is switched unconsciously from S0 to the uneven stress visualization (S2), 1–1.5 minutes after the task starts. The stages of visualization quietly and gradually transit without disturbing the participants.

4.4.3 Procedure

At the beginning of the study, we introduce to the participants that the study is about group stress. All the participants are asked to perform a series of tasks as a group. Meanwhile, the group's stress status during tasks will be visualized on the clock hanging on the wall. Because the participants have limited time for each task, they are expected to check out the clock (visualization) frequently while finishing their tasks. After all three tasks are performed, an interview is conducted to gather feedback from all participants. Questions such as "have you check out the time", "can you relate the group stress status with the visualization", "how do you feel after seeing the visualization", and "how do you interpret the different stages presented on the visualization" are asked and recorded.

4.4.4 User Feedback

Static visualization: The static visualization brought peaceful feelings to most participants, and they reported that it has less interruption of their ongoing work. Half of the participants (4/8) mentioned that they like the feeling of the static pattern and it won't disturb their ongoing work. Comments from participants include "It looks nice. I like the natural feeling of irregular patterns than a digital one." "The thing I like more is it's different from what I saw before. It's new, the material." "I can't imagine how comes up with this idea, the sand, the appearance looked more attractive." One participant (P1) commented "There's a lot of directions and lines, must indicate stress, is it?" "There's a lot of patterns over there so it's stress, but the flat one likes empty, so very peaceful." "This means half of us stressed and half are not stressed." "Right now it's all stressed!" One (P7) also mentioned "I realize this scene is much easier for me to understand the stress status." Most participants (6/8) described the influences of the static pattern on their internal activities. "I feel the flat pattern made me more relaxed compared with the striped one. Because it feels like some kind of scratches." "It has kinds of regulation, it reminds me of meditation, like the Zen garden." Most participants (6/8) claimed that they could hardly associate the stress status with the static pattern without clarifying the announcement in the beginning. Since we intend to apply positive metaphors to visualize something negative in life, it is necessary to declare the initial intention of the expression in advance. Otherwise, the expressions will be too abstract to be accepted by the audiences. Overall, the feedback shows that the static visualization could help people adjust their inner peace through public display as a means of visual intervention. The relation between the visualization and the stress needs to be improved since most of them claimed that they did not feel connected to the visualization in the first place.

Dynamic visualization: Participants hold split opinions about the dynamic visualization. Part of them claimed that they like the dynamic feedback, and they felt that it looks like real-time heart rate, while there are participants who also brought up that the quick changing shapes distract their attention in some way. Many participants (5/8) mentioned that the dynamic pattern looks like a symbol of time pressure. One participant (P3) commented that "Now it's like somebody is telling you that you need to hurry up." One participant (P4) claimed that it symbolizes the group's heart rate "Is it the group's biomedical signal? It reminds me of heart rate." Some participants (2/8) stated that stress information is useful to themselves to better cope with it because it is unnoticeable. For example, one (P1) commented that "Stress is very unconscious, it's hard to aware of my feeling that I'm under stress, but when I think about it, I can control myself and try to manage it." On the contrary, some (P5) claimed that offering collective stress information will bring more stress. For instance, a participant (P8) said "I would be more stressed if I see other people is under stress. Stress display might make me anxious, that I should be stressed as the same." In summary, the dynamic stress visualization could easily get people's attention and is accessible to provide stress information. One thing that needs to be designed carefully is to what extent the dynamic expression may produce disturbance to people.

4.4.5 Summary

The reactions and feedback gathered from the participants suggest the pros and cons of the two visualizations. The static visualization delivers a peaceful and calm status that attempts to balance users' inner peace, but it could be easily neglected. The dynamic visualization is more noticeable, but, meanwhile, it might produce unwanted interruption and disturbance. Constructive suggestions such as customization were also brought up. Some participants (4/16) mentioned that they expect to see the relation between their individual stress statuses and the collective stress information. Alternative expressions in the visualization and different modalities of biofeedback as well as more applications of this visualization were also suggested in the interview.

4.5 Discussion

The visualization presented in this chapter can be provided based on the data collected from the calendar or schedule of a team with proper synchronization between the installation and the global time. However, to tailor the visual experiences as a more proactive and adaptive design intervention for teamwork, additional sensor data should be considered to give more accurate and responsive feedback. We herein discuss the possible sensing extensions regarding reliability and scalability.

Regarding reliability, intrusive ways to sense organizational stress through HRV and EEG could be relatively stable and reliable indicators of stress. However, their original form appears to be not very practical in the context of teamwork, because everyone has to put on the device while working, and the device's form factors may negatively affect their working performance. Therefore, future research can consider developing wearable HRV and EEG devices in better forms, making them comfortable and even fashionable to be worn in daily lives and the workspaces to facilitating data collections.

Regarding scalability, nonintrusive sensing methods such as using cameras and computer vision techniques track the emotion of multiple workers by tracking their motion and facial expressions as stress indicators. A possible way to embed sensors is to use accessories that people need inevitably in their daily lives, such as designing biosensors as smart things (e.g., pillow, mirror), to minimize intrusions and distractions. The advantages are that multiple users can be tracked using a single device and the users require no instruments on their body. However, the downsides are that the users are constrained by the sensing range and it may raise privacy concerns. Hence, the physical form and the data collection mechanisms of the stress collectors should be carefully considered and designed.

Another scalable solution is to design social interaction platform for workers to report their stress situations and give suggestions to their peers easily. For example, when the atmosphere is getting uncomfortable, workers can quickly share their feelings through a platform, and the visualization will be pushed to the potential stressors' personal devices. In this case, no extra hardware deployment and maintenance costs are required because human users can be considered as sensors of collective stress. And the potentially biased conclusion from one reporter can get corrected by combining the perspective of peers (e.g., such as the collective editing platform, Wikipedia). This solution can also be considered in immersive AR or VR applications because the visualization can be provided to the users' wearable displays.

4.6 Conclusion

This chapter presents ClockViz, an augmented reality installation applying static or dynamic projection overlays, which are designed to reflect collective stress through providing biofeedback visually. Both of the proposed static and dynamic visualizations can be applied in the environment as an ambient installation that expresses the collective stress information visually. The results of a pilot study with sixteen participants suggest that the visual information of collective stress status increases participants' awareness of collective stress status and that it has meaningful influences on participants. We also have discussed the sensing solutions, which may extend the proposed techniques toward more proactive and adaptive applications for interactive design interventions for coping with collective stress with time. Future work can consider investigating how public visualization affects people's thoughts and behaviors and how personalization and customization could be conducted in the next iterations. This chapter confirmed the value of an integrated visualization in raising awareness of collective stress. It shed light on a new direction that needs to be noticed and emphasized in future research. In the next chapter, we will explore stress-related physiological stress sensing and feedback design.

Chapter 5

Designing for Stress Collection and Feedback[1]

In the previous chapter, we explored visualizing collective stress for a group of office workers during teamwork. In this chapter, we focus on stress-related physiological data sensing and feedback design in order to quantify stress data to raise users' understandings toward stress management. We present the design of "BioFidget", a biofeedback system that integrates physiological sensing and display into a fidget spinner for respiration training. The design transforms a fidget spinner into (1) a nonintrusive heart rate variability (HRV) sensor, (2) an electromechanical respiration sensor, and (3) a physiological stress-related information display. The combination of these features enables continually engaging experiences of respiration training through the designed tangible and embodied interaction. This chapter shapes our understandings of stress-related physiological data collection and guides our future physiological stress-related data visualization design.

[1]This chapter is based on the publication:
Liang, R. H., Yu, B., Xue, M., Hu, J., Feijs, L. M. (2018). BioFidget: Biofeedback for respiration training using an augmented fidget spinner. In Proceedings of the 2018 CHI conference on human factors in computing systems(pp. 1-12).

5.1 Introduction

People encounter stress in daily life, especially when they are confronted with challenging tasks. When the stress exceeds our coping ability [Monat and Lazarus, 1991], we feel anxious, fearful, and angry. In the long term, the accumulation of these negative stresses leads to the development of serious illnesses [Lupien et al., 2009]. Hence, stress management is an important topic for physical and psychological well-being.

Stress management programs seek to engage the users in ongoing self-regulation. However, the key challenge is that users often drop out of these programs. HCI researchers attempt to build interactive biofeedback systems as an intervention solution to address this challenge. These systems provide user-friendly representations of the physiological signals to increase the users' awareness of their inner states, and help them to adjust their behavior with the adaptive feedback. Providing biofeedback for respiration training is clinically proved to be effective for stress reduction [Gevirtz, 2013b]. A user who consciously employs this biofeedback technique and paces his or her breathing at around 6 breaths per minute (0.1 Hz) may regulate his or her heart rate at a resonant frequency [Lehrer et al., 2000], which maximizes the efficiency of pulmonary gas exchange and relaxes the responses of the autonomic nervous system.

One of the requirements for a biofeedback respiration training system is the utilization of a reliable physiological sensing mechanism. The reaction of a user experiencing stress can be observed from heart rate variability (HRV) [Cacioppo et al., 1996, Sharma and Gedeon, 2012], which can be detected using a pulse sensor with precise timing control; in addition, the way the user regulates his or her breathing pattern for stress reduction can be detected using a respiration sensor. However, the user has to attach these sensors to his or her body before the sensing measurement starts. The effort involved in deploying these devices seems to constitute a threshold for enabling a casual means of stress management.

We present BioFidget (Figure 5.1), a biofeedback system that integrates physiological sensing and an information display into a smart fidget spinner for respiration training. The fidget spinner, invented by Hettinger in 1993 [Hettinger, 1993], is a casual finger toy that is designed for play and stress reduction. A user can take it out from his or her pocket, spin it with little effort, and hold the center pad while it spins. During the rotation, the momentum of the toy provides a pleasant visual-tactile sensory experience. Unlike other conventional eyes-free fidget devices (e.g. fidget cubes, clickers, pens), fidget spinners provide immersive visual feedback, inertial tactile feedback, and adequate form

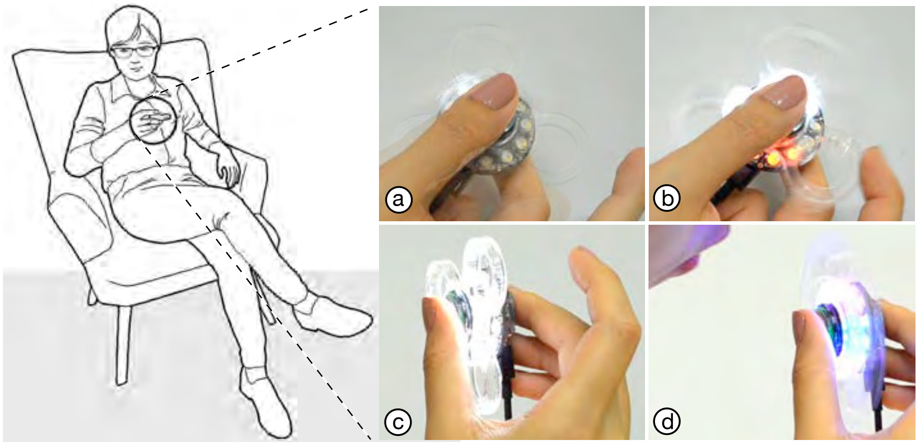


Figure 5.1: BioFidget is a biofeedback system that integrates physiological sensing and display into a fidget spinner for respiration training. The user (a) activates it with a finger flicking, (b) reads her stress-related heart rate information from the display, (c) erects it to switch it to the training mode and moves it to the mouth, then (d) blows it for breathing training with the adaptive visual feedback.

factors that allow for holding still while playing. These unique features make a fidget spinner highly advantageous in designing tangible and embodied interactions that engage casual users.

Figure 5.1 shows the usage scenario of BioFidget. When a user feels stressed, she takes out a BioFidget from her pocket and spins it to enjoy the visual-tactile experience. After several seconds, she visually observes the change of her heart rate (the white part) and her pulse (the red part) from its display. Then, she re-orients the BioFidget and moves it to her mouth, turning it into a respiration trainer, which guides her to take deep breathes using a rhythmic breathing light. When she exhales, the breath makes the BioFidget spin. It provides adaptive visual feedback corresponding to its speed, indicating the quality of her breathing and encouraging her to play with it again. After three minutes of a playful and relaxing experience, she puts the BioFidget back in her pocket and returns to work.

In this chapter, we emphasize the visual feedback aspect of the BioFidget system in order to generate insights for stress-related data visualization design. We integrated portable displays to augment the visual feedback of BioFidget in

Section 5.2, and we implemented it with 20 office workers in Section 5.3. At last, we discuss guidelines for future stress intervention design in Section 5.4.

5.2 Design and Implementation

Figure 5.2a shows the basic hardware that we developed to demonstrate the interaction. Each prototype device consists of a photoplethysmograph (PPG) sensor, which has proven to be effective for sensing the HRV values of healthy subjects at rest [Fabricant, 2005, Lin et al., 2014], an analog Hall sensor that senses the user's respiration through revolutions of the magnetic wing of the fidget spinner, a visual display for providing physiological information and adaptive feedback for respiration training, and an additional accelerometer for identifying interaction modes (i.e., respiration training or HRV sensing).

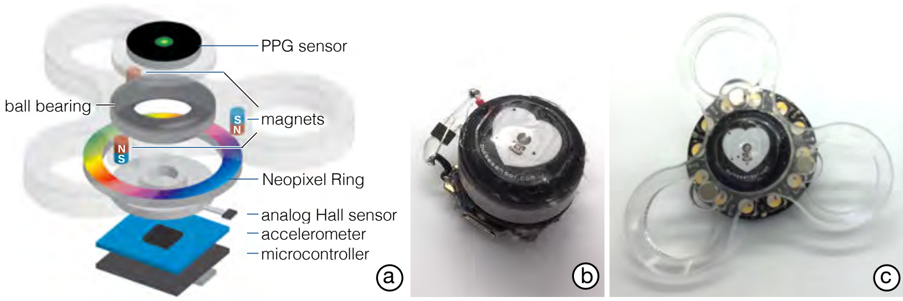


Figure 5.2: Hardware design of a *BioFidget* prototype. (a) Overview of components. (b) Center pad that consists of sensing and signal processing units. (c) Assembled state.

To provide procedural information and adapt to the user's need of respiration training, we added an extra display to provide *augmented feedback* and *feedforward* to the interactive system. Intuitive feedback and feedforward should coincide in modality, time, location, direction, dynamics, and expression [Wensveen et al., 2004]. Regarding *modality*, a visual display provides greater bandwidth of communication, so we first consider bringing a simple yet rich visual display, a NeoPixel ring[2] that consists of 12 RGBW LEDs, to augment the fidget spinner. Regarding *location*, the display is set to the center of the fidget spinner, so the user can perceive the provided information without dragging his or her foveal

[2] https://www.adafruit.com

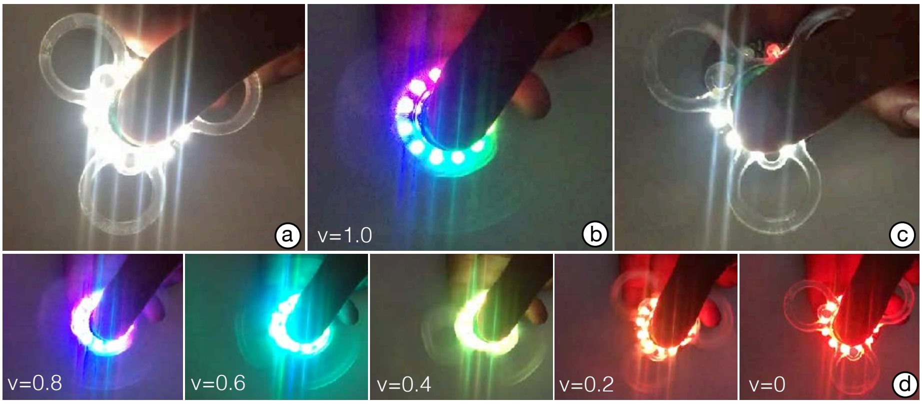


Figure 5.3: Augmented visual display. (a) The pure-white ring indicates inhalation. (b) The colorful ring indicates exhalation. (c) Pure-white bar with pulsing red light indicates IBI and heart beat, respectively. (d) The hue and its range change according to the revolution speed.

attention away from it. The ring display is placed under the transparent wing so it augments the physical movement instead of replacing it.

The ring displays respiration-related information when the BioFidget spins within the last 10 seconds (one complete cycle of respiration). To guide the users to perform the right *direction* of interaction at the right *time*, the visualization should clearly indicate the current state (i.e. mode), what to do next (i.e. feedforward), and the effects caused by the performed action (i.e. feedback). We choose three independent parameters: color channel, brightness, and hue to present these types of information. In the respiration training, the ring indicates inhalation and exhalation using two independent channels, monochrome (pure White) and color (RGB) respectively (5.3a and 5.3b); the ring indicates breathing speed and timing t through a steady, linear function $brightness(t)$ in both modes as feedforward; the ring also indicates the revolution speed v as feedback of exhalation quality using a colorful ring in a different range of hue through a linear function $hue(v)$ (5.3d) as

$$hue(v) = \begin{cases} [.25v,\ .75v] & \text{if } 0 \le v < 1 \\ [0,\ 1] & \text{if } v = 1, \end{cases}$$

where both $hue(v)$ and v are clipped with bounds and normalized to $[0,1]$ for generalization. Finally, regarding *dynamics*, the colorful ring also rotates according to the speed of the fidget to adhere to the physical movement of the spinning fidget.

Before and after the respiration training, the fidget should display the user's pulse and HRV information as feedback and feedforward of the respiration training. Regarding the *direction* and *time* of interaction, if the BioFidget did not spin in the last 10 seconds, the fidget guides the user to place his or her finger on the green LED of the PPG sensor by turning the ring display off, and to wait by showing a loading animation. The *expression* of IBI and pulse information has two parts: a 10-scale, clockwise monochrome bar showing the IBI between 500ms and 800ms in real time for the visibility of subtle HRV changes (between 30ms and 50ms) with respiration training, and two fading red (colorful) LEDs to mimic the *dynamics* the pulse (5.3c).

We further present several alternative designs that utilize various physical forms to optimize these biosensing and biofeedback features; these physical features include a clip to stabilize the PPG sensing (Figure 5.4b), a fan-shaped wing to increase the sensitivity of the device to respiration (Figure 5.4c), and a handheld display to enrich the visual expression of biofeedback (Figure 5.4d).

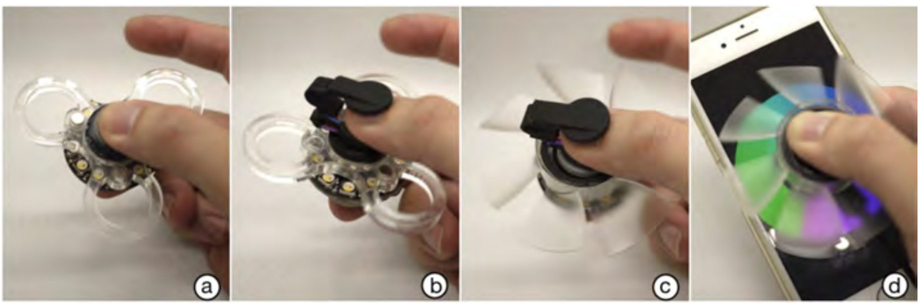


Figure 5.4: Alternative BioFidget designs. (a) Basic design. (b) BioFidget with an additional clip for PPG sensing stabilization. (c) Fan-shaped wing to react to respiration. (d) BioFidget with a handheld display for rich visual biofeedback.

Portable displays can be integrated to augment the visual feedback of BioFidget. These high-resolution displays can provide rich visual biofeedback expression, and the embedded sensors and actuators (e.g., speaker) can enrich the *modality* of interactivity and increase the level of embodiment. One of the best *locations* to place the BioFidget is on the screen so that the nearby visual feedback can directly augment the experiences of training. With reliable communication, the signals can be provided at the right *time*.

Figure 5.5a shows a user using a smart phone that produces the aforementioned visual display. The 4.7-inch smartphone display renders a high-resolution colorful ring, which preserves the features of *direction*, *dynamics*, and *expression* of the visual design introduced in the previous sections; moreover, the rich visual display is collocated with respiration guidance and feedback (Figure 5.5a and 5.5b), which the users can perceive simultaneously using both their foveal and peripheral vision; furthermore, it also provides *historical* HRV information (Figure 5.5c). Based on the principle of RSA [Yasuma and Hayano, 2004], we designed a simple example of IBI visualization as biofeedback for respiration training. Figure 5.5d and 5.5e show an overlaid IBI and revolution speed graph, which is drawn circularly in 1.2 rpm. The visualization shows the IBI with the fidget revolution speed in the last N = 5 breathing cycles. During the respiration training, the oscillation phases of IBI and the respiration synchronize as a five-petal flower on the screen (Figure 5.5d), which allows the user to evaluate the heart regulation with the visual feedback received from the respiration training. This infrastructure enables various forms of presentation, such as aesthetic, metaphorical, or poetic biofeedback [Yu et al., 2016a].

Figure 5.5: Smartphone implementation. (a) The progress of inhalation. (b) The progress and the quality of exhalation. (c) Visualization of HRV (red) and respiration (blue) information. (d) Results of adequate respiration training. (e) Results without respiration training.

5.3 Evaluation

To evaluate whether the proposed system meets the requirements of sensing validity and engagement, a series of studies were conducted. The results from a 32-participants user study showed that the proposed Biofidget device is a reliable and valid intervention that effectively supported respiration training and caused positive effects on stress reduction [Liang et al., 2018a].

In this chapter, we focus on one of these studies to understand how users experience the stress-related data visualization and facilitate stress awareness. The study was conducted with a subset of 20 participants from the previous study (11 females, 9 males). The mean age of the participants was 28.19 (SD = 1:63). All participants had experiences of using the basic BioFidget with or without a clip (Figure 5.4b or 5.4a, respectively). In this study, they were asked to use the fan-shaped BioFidget (Figure 5.4c) for respiration training. Using the implementation shown in Figure 5.5, each participant was asked to place the fidget spinner on the screen of a Microsoft Surface Pro tablet, which was horizontally placed on a table, so users could place an index finger on the center pad of the fidget to use it. Each participant received instructions on how to perform the respiration training, and how to play with the fan-shaped BioFidget before each session. Then, the participant performed a 1-minute baseline session where each participant was asked to watch their IBI on the display (Figure 5.5e). Afterward, the participant performed a 1-minute Blow session with the respiration information on the screen (Figure 5.5d). The on-screen visualization (Figure 5.5) was provided during and after the respiration training, and the NeoPixel ring of the fan-shaped BioFidget was turned off; thus the users simply followed the on-screen guidance. After the two sessions, each participant received an explanation of the HRV visualization and was asked to describe the experiences through a short interview.

According to the interview results, 18 (out of 20) participants reported that the fan-shaped BioFidget was easier to blow on than the basic BioFidget, and another two reported that they were equally easy to blow on. This result reveals that the fan-shaped BioFidget better supports effortless and smooth exhalation. 18 participants could tell the correlations between their breath and IBI patterns and agreed that respiration training could be helpful for heart rate regulation. When participants use the tablet for respiration training, their colleagues can see their performance. Interesting interactions among peers in terms of comparison was found. When one participant is using the BioFidget, his or her peers got attracted and curious by what he or she is doing and suggested they also want to try by themselves. They compared with each other on who's 'flower' is more pretty afterward. 9 (out of 20) participants wanted to try it again because they wanted to improve their results (i.e., HRV). The results implied the potential benefits of visualizing stress in a social context in engaging and motivating users to manage stress.

5.4 Discussion and Conclusion

Extensions of the Biofeedback and Biosensing. The expressivity of biofeedback of the current implementation is limited by the 12 RGBW LEDs. An alternative design might use a high-resolution OLED Display or a persistence-of-vision (POV) display to provide richer information. One can also consider leveraging additional screens to provide contextual information in a higher level of embodiment: For instance, a smart TV or a vertical projection screen might be distant from the user, or a tabletop/tablet display might allow the user to spin a BioFidget on it and get detected [Liang et al., 2013]. One should also consider using ambient light bulbs, auditory displays (i.e., speakers), tactile displays, or shape-changing displays to augment the experiences further.

RSA Visualization in Training. For the consistency of user experiences, the smartphone screen only presents breathing guidance and feedback during the training as the screen-less one; therefore the RSA-like visualization is only shown as the history of a user's interest in the end of training. The results of an informal test with several users show that they can perform breathing training correctly when they are watching the progress of the flower-shaped drawing, but as a side effect, it reduced the immersion of training because the user had to comprehend what the two curves might mean. Thus we recommend keeping the visualization as simple as possible and leaving its optimization for future work.

Advanced Intervention of Stress. This work demonstrates an adaptive and playful design intervention as a means of stress management for individuals. The user gets real-time biofeedback that closes the loop of the execution and evaluation [Norman, 2002]. However, a more sophisticated incentive mechanism should be considered to facilitate better long-term stress coping; this may be accomplished by motivating meaningful behavioral changes in users regarding problem-focused coping [Monat and Lazarus, 1991]. Multiple users can also use their own BioFidgets (either in a remote or collocated way) while their stress-related data are collected. This collective stress [Lansisalmi et al., 2000b] information could be valuable for understanding the socio-technical issues within a group of users, which, in turn, could be used to help them cope with their common stressors and increase their productivity and health.

This chapter introduces BioFidget, which integrates biofeedback, biosensing, and respiration training mechanisms into the form of a fidget spinner. The results of technical and preliminary user testing show that the proposed system and method provide valid and playful experiences that turn a popular toy into a useful stress management tool. It contributes insights for our future stress-related data sensing and visualization design. After this chapter on personalized stress sensing and feedback design, we move towards collective stress coping in the next chapter.

Chapter 6

Designing for Collective Stress Reflection[1]

In the previous chapter, we explored personalized stress sensing and physiological stress visualization design. This chapter explores how to support office workers' reflection on collective stress through visualization design. Specifically, we deploy the stress data collection techniques presented in Chapter 5, to collect individual user's physiological stress and visualize them collectively on a shared display to multiple users. A minimalist proof-of-concept system is implemented for investigating the design space and deployed during group collaboration. This chapter highlights the importance of objective physiological data in the reflection process of collective stress management.

6.1 Introduction

Nowadays, stress management has become a growing concern for office health. Office workers often suffer from chronic stress caused by, e.g., excessive workload, position changes, and unemployment risks. Physiologically, prolonged stress may break the balance of stress hormones, unbalance the autoimmune system and contribute to cardiovascular diseases. These stress-related factors

[1] This chapter is based on the publication:
Xue, M., Liang, R. H., Yu, B., Funk, M., Hu, J., Feijs, L. (2019). AffectiveWall: Designing Collective Stress-Related Physiological Data Visualization for Reflection. IEEE Access, 7, 131289-131303.

may also reduce working performance. Beyond the individual stress, collective stress [Lansisalmi et al., 2000b] is another type of stress within an organization or group. Common stressors in an organization could be interpersonal, such as different types of peer pressure and social comparison [Festinger, 1954]. These stressors could highly affect the interpersonal and intrapersonal emotional status, reducing job satisfaction of office workers and weakening organizational competitiveness. Thus, stress management has received extensive attention and has been investigated widely [Al Osman et al., 2016, Ghandeharioun and Picard, 2017, Lansisalmi et al., 2000b, Liang et al., 2018a].

As the human physiology reacts to stress, measuring stress-related biometrics and presenting the related information back to the users can facilitate self-reflection on and self-regulation of stress [Al Osman et al., 2016, Brown, 1977, Liang et al., 2018a]. Some researchers have claimed that the key issue regarding stress management is mirroring the stress to people in order to promote self-reflection rather than finding ways to diagnose the stress [Sanches et al., 2010]. Such tools that help people collect and reflect on their personal information were defined as personal informatics (PI) systems [Li et al., 2010a]. PI systems emphasize self-tracking and self-reflection. As the whole process is operated by the individuals themselves, potential subjective validation bias is inevitable [Klayman, 1995] during this self-reflection process [Kersten-van Dijk et al., 2017]. As a result, subjective interpretations of oneself may lead to inefficient self-awareness and biased reflection, which might result in a negative loop and hinder further behavior changes.

People who are situated in a shared context will take others into consideration in the interactions, and regulate themselves in their actions [Niemantsverdriet et al., 2018]. Therefore, we assume that interpreting a PI system as a collective system in a shared context can help people gain a better understanding of both self and collective stress. To investigate this assumption, this chapter presents a conceptual design, *AffectiveWall* (Figure 6.1), a shared visualization that facilitates the reflection of collective stress by visualizing the combined individual worker's stress-related physiological signals as a collective.

Figure 6.1 shows the example scenario. In the coffee room next to an office, AffectiveWall works as a shared display that visualizes the office workers' stress information over time. When colleagues enter the coffee room to take a break from work, they will notice their own and their peers' stress levels and the changes over time. For instance, an employee finds out she is the most stressed person among her peers, and the whole group is under too much stress. This feedback may trigger her to take further actions to manage the underlying stress factors, such as talking to someone. During tea-time, the group members can reflect on their stress patterns and brainstorm what to do after work together.

In the visualization, we mapped the individual's collection of physiological measures of the stress-related index (heart-rate variability, HRV) to the timeline, aiming to show a collection of the repeated physiological measures from multiple users. To facilitate the users in reading their stress status from the collective visualization, we correlate the stress-related index to the size of the pattern while preserving the time-series information. This allows one to easily compare his or her stress level in the collection, both inter- and intra-personally. To avoid additional peer pressure being induced during the interpretation of the visualizations, all the stress patterns are anonymized. The user can only access his or her own stress information and a group stress overview; a user's personal stress information cannot be accessed by others.

In this chapter, we identify the parameters for visualizing the stress-related information as a collective through two exploratory online questionnaires in

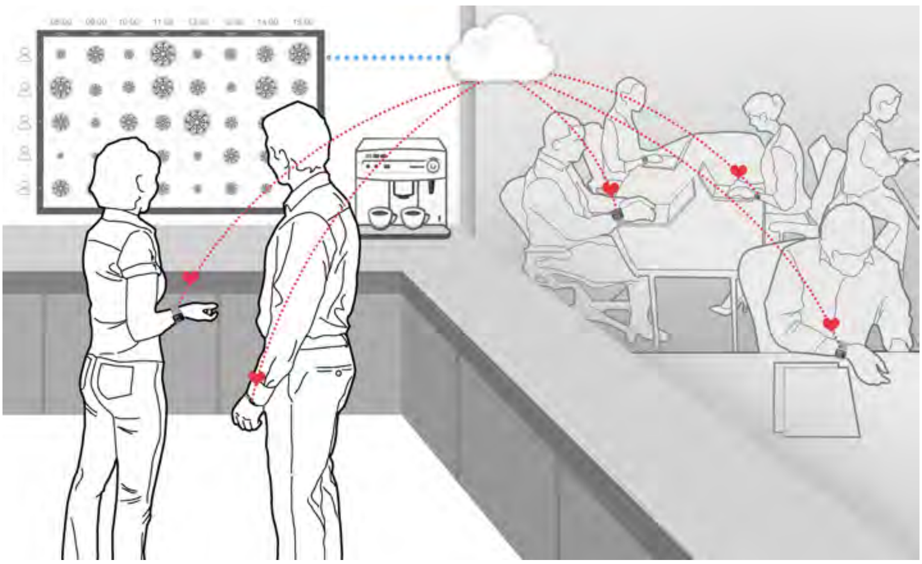


Figure 6.1: Example scenario of a collective stress-related visualization that shows a collection of peers' individual stress. Based on the collective stress-related signals from the users, an anonymous visualization related to the individuals in their workgroup is shown collectively in the coffee room. People discuss their stress levels with their colleagues during the break.

Section 6.2. Then we implement a proof-of-concept prototype and test it in a formal user study in Section 6.3. In Section 6.4, we discuss the remaining barriers of the system using the stage-based model [Li et al., 2010a] and potential ethical issues to deploy this system in the field.

6.2 Design and Implementation

This section first describes the design considerations based on the related work. Then we describe the design of AffectiveWall, a collective visualization for workplace stress management following the five stages of the PI model.

6.2.1 Related Work

In HCI, stress management can be realized through personal informatics (PI) systems [Li et al., 2010a, Chrisinger and King, 2018] and biofeedback systems [Kudo et al., 2014, Smith, 2014]. Reflection is the necessary stage towards taking action — stress management. The current PI system supports self-reflection; however, self-reflection inevitably exhibits subjective validation bias [Forer, 1949], as one will consider a statement or another piece of information to be correct if it has any personal meaning or significance to oneself. Problems that occur in the reflection stage will disable further action [Li et al., 2010a] — in this case, stress management. For example, unrealistic self-expectations may lead to a biased self-reflection, and even worse, may incur extra pressures on oneself. Group reflection could be beneficial for people to discover a phenomenon that is sometimes difficult to observe individually or subjectively [Fleck and Fitzpatrick, 2009, Branham et al., 2012, Isaacs et al., 2013]. To avoid biased self-reflection, we can consider the reflection process in a shared context, as people will take others into consideration in the interactions, and regulate themselves in their actions within the shared context [Niemantsverdriet et al., 2018].

6.2.2 Design Considerations

Based on the related work, we consider that the design of visualizing individual stress in a collective context should meet the following three criteria: *validity of collection*, *readability of integration*, and *being stress free*.

- *Validity of Collection.* The design should depict the individual's and group's stress status meaningfully with valid stress markers. Only when the validity of the data collection is mapped with the ground truth the data integration can be meaningful for the users and their community.
- *Readability of Integration.* The design should clearly integrate the individual stress data and group stress data for the users at a glance, which is especially appreciated by the office workers in the workplace scenario.
- *Being Stress Free.* The design should not bring extra stress among the users during the interpretation and discussion. Only when the experience is stress-free, the users can comfortably share their status and feelings with each other, and it is more likely to trigger further actions on stress management.

6.2.3 Designing Collective Stress-Related Visualization

We aim at designing a collection of individual office worker's stress-related visualization in a shared context, such as a workspace. The primary design challenge is how to enable the workers to make meaningful inter- and intra-personal comparisons without inducing additional peer pressure.

Design

Regarding the *validity of collection*, we use the HRV as an objective physiological stress marker [Sloan et al., 1994]. The inter-beat interval (IBI), which can be precisely computed using a conventional PPG [Lee et al., 2012, Charlot et al., 2009] sensor and a micro-controller preloaded heartbeat detection algorithm, is used in this installation. The *validity* of the data collection is based on the assumption that there exists infrastructure of continuous collective HRV sensing, data collection, and the network-connected public display, as shown in Figure 6.1. Regarding continuous sensing, the sensor should be made into a wearable form so that the measured data can be collected continuously. Such an infrastructure can be realized by requiring each worker to wear a network-connected PPG-sensing device, which can reliably monitor the user's HRV in the background of their everyday activity and periodically synchronize the HRV data to the Cloud server, and thus the data visualization can be realized on the network-connected public display.

Regarding *readability of integration*, to enable meaningful inter- and intra-personal comparison, we intend to map the individual's HRV patterns onto a timeline so that the stress from different people that happened at the same time is comparable. Figure 6.2 shows an example 2D view of stress-related visual patterns, where the x-axis represents the timeline and the y-axis represents the participants. In this view, a user could backtrack his or her historical stress status and compare his or her stress status with others, and further observe the group stress through the overview.

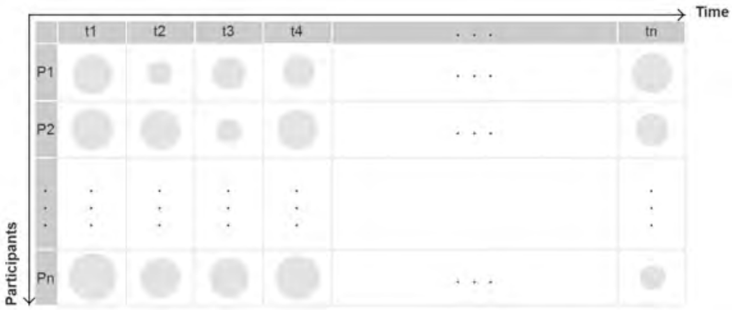


Figure 6.2: Example spatial arrangement of stress patterns in 2D. X-axis: time. Y-axis: anonymized individuals.

For the pattern design, we first consider a fixed-duration (e.g., 5 minutes) discrete measurement for simplicity. We want to preserve the time-series HRV history for reflection, and therefore we design the following three minimalist patterns: P_{IBI}, P_{SDNN}, and $P_{SDNN+Ring}$.

P_{IBI}: The IBI data collected from the PPG sensor are mapped to the angle and length of lines, which are then arranged clockwise as a round pattern. The θ of the n-th data in the pattern is set to $\theta = n \times \frac{2\pi}{N}$, where N is the total number of data. The length l of a stroke is obtained from IBI (Figure 6.3b). In this case, integrating a large amount of data in a round pattern allows for a clearer view and easier comparison.

P_{SDNN}: To map the HRV to the size of the pattern, the length of each stroke is determined by $SDNN16$, the Windowed (W=16) Standard Deviation of interbeat (NN) intervals. The window size $W = 16$ is chosen because it is large enough to include at least one complete respiratory circle and small enough to be sensitive to changes in the breathing pattern [Yu et al., 2018b] (Figure 6.3c and Figure 6.4c).

$P_{SDNN+Ring}$: The mean SDNN, $\overline{SDNN}$, which could represent the overall HRV during the measurement, should also be mapped to size. Therefore, the $P_{SDNN+Ring}$ model (Figure 6.4b), which has an additional overlaid circle is de-

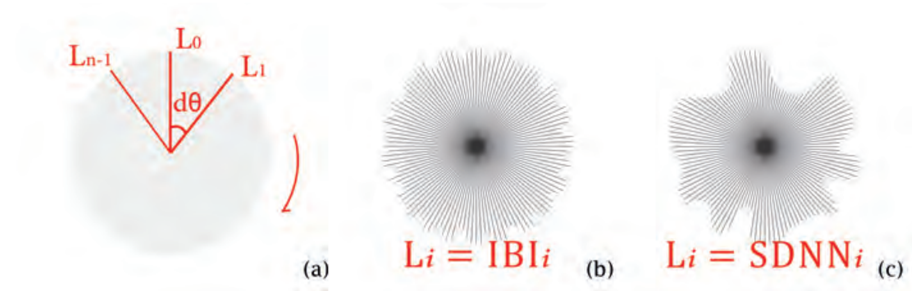


Figure 6.3: Single-layered patterns. (a) Model representation. (b) P_{IBI}. (c) P_{SDNN}.

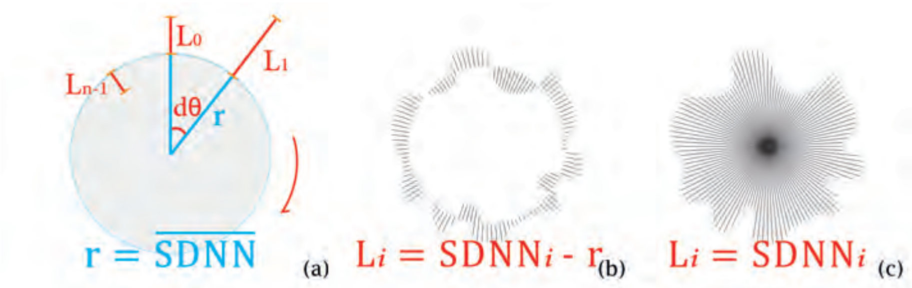


Figure 6.4: Single-layered patterns enhanced by $\overline{SDNN}$. (a) Model representation. (b) $P_{SDNN+Ring}$. (c) P_{SDNN}.

signed to enhance the readability of the overall stress of the P_{SDNN} pattern.

Regarding *being stress free*, peer comparisons are likely to arise, and the personal information shows in a smaller workgroup could also lead to peer pressure. Therefore, we apply anonymity [Suler, 2004] to avoid extra stress from these social factors. The visualization does not reveal personal information, such as names. Instead, different avatars are shown on the screen so that the users could recognize the differences between individuals data. Every user hold the identity of his or her avatar privately (e.g., through their personal devices), therefore each user knows his or her data but does not know the identity of the others, just as the others do not know which data is from the user. The identity of the avatars could shuffle periodically (e.g., daily) so the users could prevent others from knowing the ownership of an avatar.

Explorative Study

Two online questionnaires were used for understanding how effective the users perceived different types of stress visualization to be (see Appendices B.1, B.2). Both questionnaires were started with instructions on the study, the data sources, and an example question to facilitate the participants in recognizing the stress pattern. At the end of both questionnaires, a feedback section was provided to engage the participants to express their feelings on the stress visualization freely.

Questionnaire 1 (Appendices B.1) tested whether the P_{IBI} pattern or the P_{SDNN} pattern design was more accurate in presenting the stress-related data. Questionnaire 2 (Appendices B.2) tested whether the additional information $P_{SDNN+Ring}$ could help judgment of the stress level. The questions were generated using a database of 14 users' 3-minute IBI data (500ms - 1250ms), none of whom had a missing beat. We first ranked these data using their $\overline{SDNN}$ value from the highest to the lowest, generated their P_{IBI}, P_{SDNN} and $P_{SDNN+Ring}$ patterns accordingly, and separated them evenly into two smaller sets, A and B, as shown in Figure 6.5. The seven patterns in each group were used for generating 21 single-choice questions, in which the participants need to identify which one was more stressful. Figure 6.6 and 6.7 show examples of the questions. The order of each question was within-subject randomized. The question sets A and B were between-subject counterbalanced. The participants of the two questionnaires were recruited separately from a university mailing list and social network. Both questionnaires were answered online.

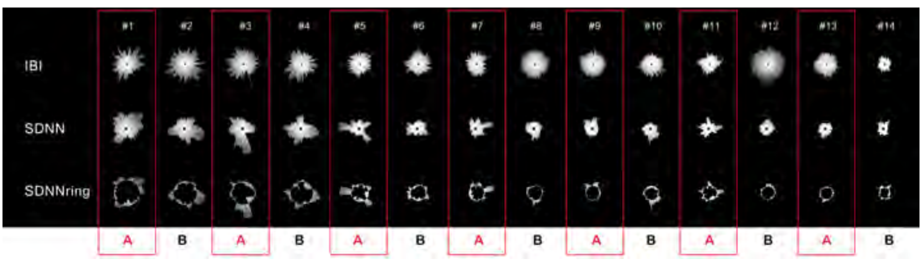


Figure 6.5: Database of 14 participants' 3-minute IBI data. P_{IBI}, P_{SDNN}, and $P_{SDNN+Ring}$ patterns were generated and categorized into two groups based on the ranking of $\overline{SDNN}$ from the highest (left) to the lowest (right).

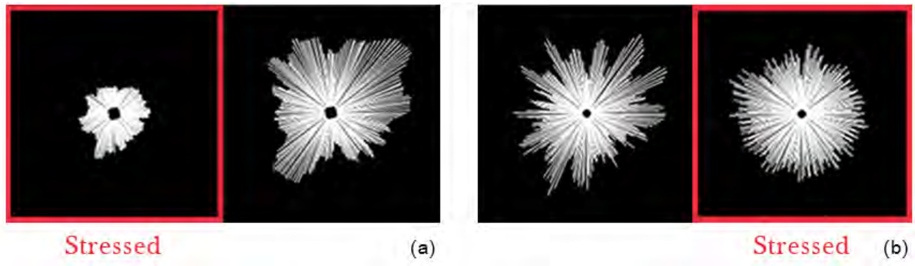


Figure 6.6: Example questions of Questionnaire 1: Choose the more stressful pattern in (a) P_{SDNN}. (b) P_{IBI}. Correct answers are indicated in red.

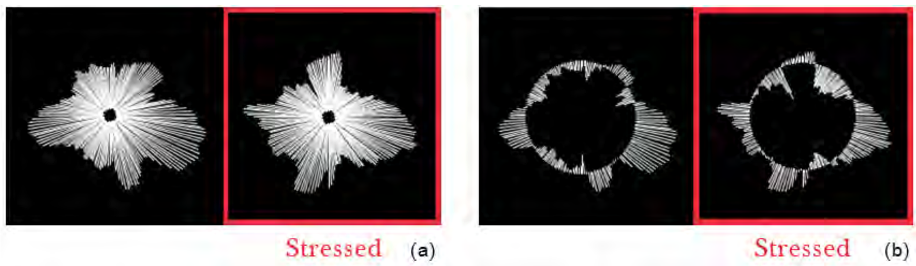


Figure 6.7: Example questions of Questionnaire 2: Choose the more stressful pattern in (a) P_{SDNN}. (b) $P_{SDNN+Ring}$. Correct answers are indicated in red.

Results

Questionnaire 1 (Q1) received 31 (19 females, 12 males) responses. A paired-sample t-test showed that, generally, P_{SDNN} patterns (93.65%) have higher accuracy than the P_{IBI} patterns (78.04%) without a statistical significance (p=0.265) (Figure 6.8). If we only consider questions with more than two-rank differences, the accuracy of P_{SDNN} patterns does have significantly higher accuracy than the IBI patterns (p=0.013). The results suggest that the SDNN pattern significantly improves the readability of stress levels.

Questionnaire 2 (Q2) received 36 (21 females, 15 males) responses. The results of a paired-sample t-test showed that $P_{SDNN+Ring}$ patterns have higher accuracy (95.87%) than P_{SDNN} (91.75%) (Figure 6.8), though, there is no significance found in either overall or any combinations of subsets between these two groups.

The user's feedback section at the end of each questionnaire reveals what

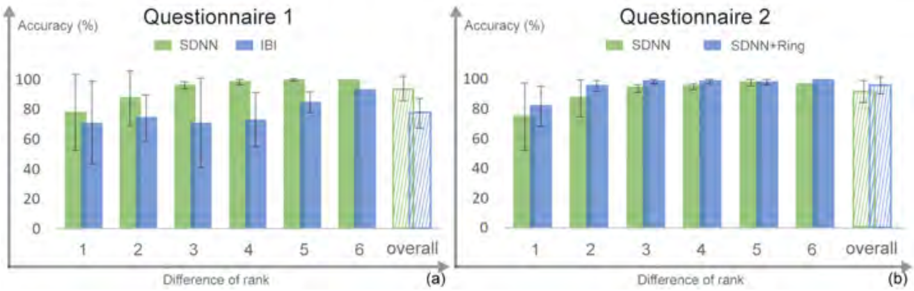


Figure 6.8: Questionnaire study results.(a) P_{SDNN} vs. P_{IBI}.(b) P_{SDNN} vs. $P_{SDNN+Ring}$ of the answers' accuracy with rank differences from 1 to 6 under the comparison of (a) size vs shape, and (b) NoRing vs Ring. 1-rank difference represents the two patterns having 0 interval pattern in between and 6-rank difference represents the two patterns having 5 interval patterns in between.

people think about these patterns. The shape of the P_{SDNN} did interfere with the user's choice, for example, *"The more asymmetric they seem, the more stressful they appear to me."*(Q1P30). *"If it had one line that was farther out than others that bothered me more than the smaller ones"*(Q1P14). Some mentioned that the ring could increase the accuracy of their judgment, *"I think the ring size was most clear to me"*(Q2P35), while some mentioned that the ring makes the $P_{SDNN+Ring}$ shape *"visually clearer because of the circle but less interesting"*(Q2P14). Some participants felt an emotional connection because the patterns are visualized from real heartbeat data, for example, *"I would like to have a ring of my own heart"*(Q2P36). *"Mainly curious whether these visualizations are based on real heartbeats and curious what mine would look like!"*(Q2P31). About the mappings, although most of the participants did it correctly, some participants thought the visualization counterintuitive. For instance, *"I would expect that the bigger, flexible flowers would present more stress"*(Q1P20), *"I feel more stressed when I see bigger rings"*(Q2P19) and *"For stress, my intuition says that small means good, whereas big means bad."*(Q2P32).

In sum, we conclude that both P_{SDNN} and $P_{SDNN+Ring}$ patterns did provide better readability than the P_{IBI} pattern. An overlay ring further improves the readability of the overall stress level. It concurred with the visual perception theory that size is more salient than shape [Healey and Enns, 2012].

6.3 Formal User Study

In our explorative study (i.e., the two questionnaires), we identified the parameters for visualizing the stress-related information as a collective. In this section, we implemented a proof-of-concept prototype, AffectiveWall, to understand how a group of users experience the collective stress related visualization for reflection through a formal user study.

6.3.1 Experiment Design

Participants

Twenty-four participants (11 females, 13 males) aged from 27-42 (M=30; SD= 3.51) who worked for a university were recruited for the study. They were divided into six groups of four. All group members were required to be colleagues to simulate a daily workplace scenario. Each group was further divided into two subgroups so that the two participants could team up and collaboratively compete with another team formed by the other two.

Apparatus

To simulate the usage scenario that we visualized in Figure 6.1, a room was prepared to simulate a working space. Four laptops were prepared for each participant (P1, P2, P3, P4) in front of four chairs. A mouse was connected to each computer for standardized one-handed input. The participants used these computers in performing collaborative tasks. Aside from each laptop, a PPG sensor (Figure 6.9) clip was fixed on the desk surface for measuring participants' HRV. The placement of the clip positioned the hand in a comfortable way for noiseless signal collection.

Each of the PPG sensors was attached to a customized operational amplifier with adjustable gain, which allowed the users to adjust the sensitivity of PPG sensing by turning the knob on the potentiometer. The beat detection algorithm was realized using the comparator circuit in this hardware design. Each module was connected to a PC through an Arduino Uno board mounted an ATMega328P microcontroller, which sampled the PPG data and the detected beats in 500Hz and sent the readings to another computer through the USB serial port. The IBI, $SDNN16$, and $\overline{SDNN}$ were calculated from the collected data and visualized on the screen in real time.

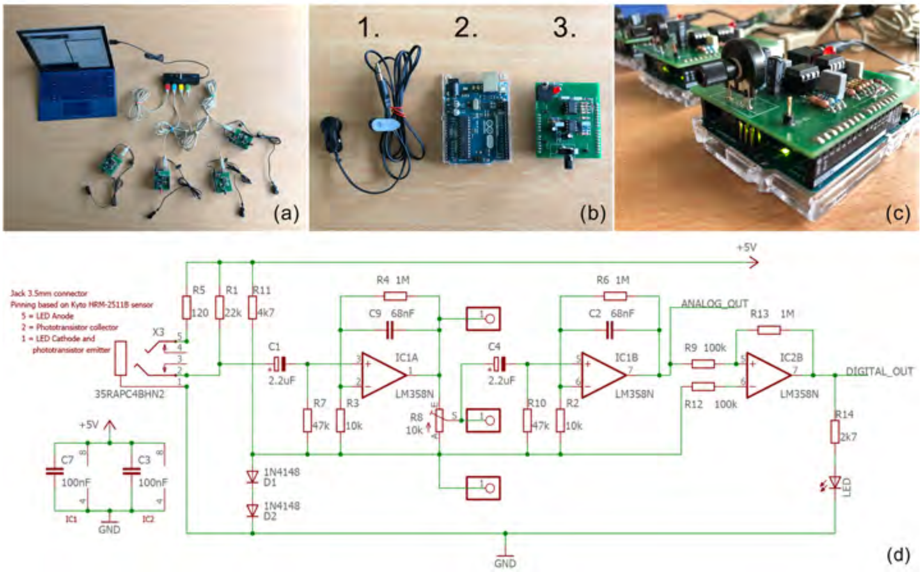


Figure 6.9: Hardware apparatus. (a) Overview. (b) Each module consisted of 1) a PPG sensor, 2) an Arduino board and 3) an operational amplifier that allows for senstivity adjustment by (c) turning the knob. (d) Schematics [Langereis, 2010].

Regarding visualization: we realized the previously proposed patterns and spatial arrangement and displayed them collectively on the wall through a projector (Figure 6.10a). The projector was hidden beneath the office desk and projected directly on the wall facing the group members. The pattern was drawn in mint green for $P_{SDNN+Ring}$, all the $SDNN16$ that were smaller than the $\overline{SDNN}$ were pointed inward and emphasized in a darker color to make the ring easier to observe. Pressing a button could toggle the display between the P_{SDNN} and $P_{SDNN+Ring}$ patterns.

Tasks

The tasks aimed to change the stress level of the participants and show them the change in their stress patterns afterward. Math challenges were used to increase their stress level by extending their mental efforts [Fooken, 2017]. Before each challenge started, participants were asked to do paced deep breathing with a

Figure 6.10: User study. (a) Results of $P_{SDNN+Ring}$. (b) Results of P_{SDNN}. (c) Apparatus.

peaceful video to reduce their stress level (task 1 and task 3). In task 2 and task 4, each participant in the two teams, [P1, P2] and [P3, P4], collaborated with his or her teammate to compete with the other team. Both sides were asked to solve the math challenges on the same shared Google spreadsheet so that everyone could see each other's progress. To motivate them to do their best, participants were informed that the winning team, i.e., the team with the most completed and correct answers, would win an additional 5 Euro voucher.

Two types of collective stress that we introduced in Chapter 4 were introduced in the team: 1) All stressed: aimed at making all the group members feel stressed, and 2) Some stressed: some members stressed while some are not. In the *All stressed* condition (task 2), both teams did a long list of two-digit multiplications (e.g., $79 \times 94 = ?$). In the *Some stressed* condition (task 4), P1 and P3 did the easier two-digit addition (e.g., $58 + 97 = ?$) while P2 and P4 did the same two-digit multiplication so that unequal tasks may cause different uneven stress levels within the groups. Every team experienced *All stressed* before *Some stressed* to avoid the uneven stress also happening in the *All stressed* condition.

Procedures

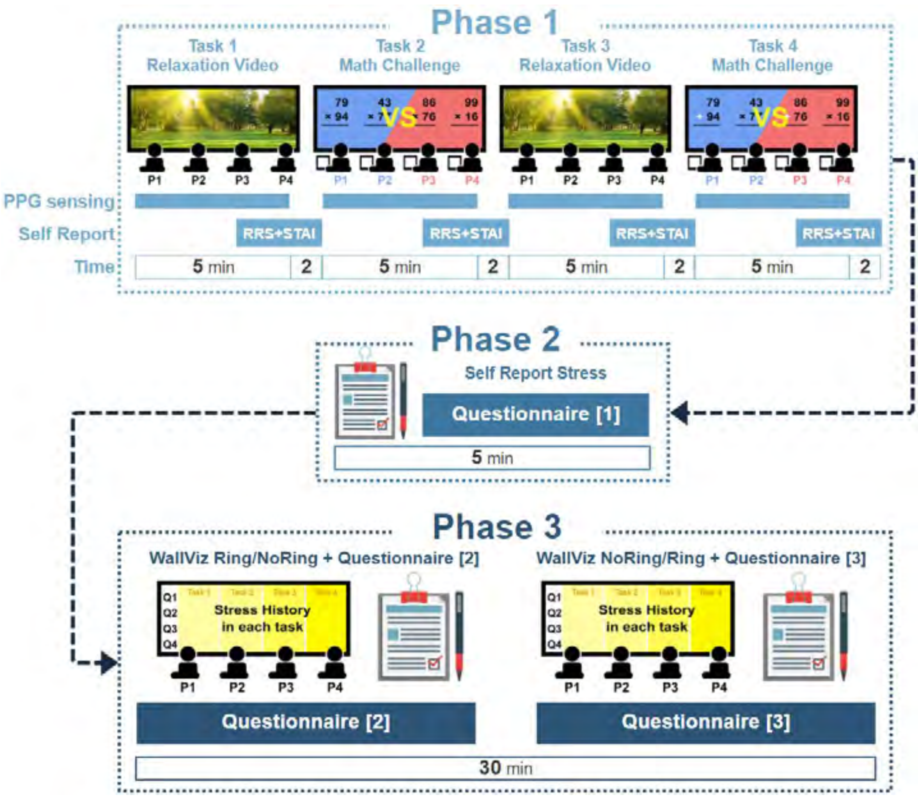


Figure 6.11: User study procedures.

All participants gave written consent prior to the user study. Before each study started, we introduced every group of participants about the study procedure, what data will be collected, and how the system works using a unified presentation. After all the group members knew how the physiological data transferred to the visualization and how to read it, the study started. Figure 6.11 shows the procedures of the whole study, which includes three phases that last for approximately 60 minutes in total. In Phase 1, which was started after the participants received the introduction, the participants were asked to finish four 5-minute tasks. After each task, the participants were asked to complete two self-report stress questionnaires (Appendices A.1: RRS, and A.2: STAI). In Phase 2, participants were asked to reflect on the four tasks in Phase 1, and rate their subjective stress level on each task on a 5-point Likert scale (1: very relaxed; 5: very stressful) in the Questionnaire 1 (Appendices B.3). In Phase 3, each participant P_i got his or her identity of *avatar* Q_i, where $Q_i \neq P_i$, which indicated the data ID (row number) in the anonymized stress visualization. Then, the stress visualization was shown to them in patterns of P_{SDNN} or $P_{SDNN+Ring}$, and the participants were asked to fill questionnaires 2 and 3, respectively. In these two questionnaires, the participants were asked again to rate their stress level on a 5-point Likert scale based on what they read, and further *rank* their relative stress level (1: I am the most stressful one; 4: I am the least stressful one) in their group. Questionnaire 2 (Appendices B.4) and 3 (Appendices B.5) share the same questions, except that the object of the questions was described as either "Ring" or "NoRing". They also gave comments on the usefulness of anonymity, reasons for their rankings and ratings, and reflections of the tasks with the visualization. During all three phases of the user study, verbal conversations were not allowed in order to reduce the extra pressures from social interactions. Nonetheless, after the participants were told the study was over, and they could freely choose to leave or stay for an optional discussion, in which our observation continued. The study paid each participant 20 Euros as compensation.

Measurements and Data Analytics

Regarding objective measurements, we measured each participant's IBI data, which were used for quantifying the stress level by calculating the SDNN. To assess the validity of the SDNN data, the beat miss rate R_{miss} was calculated from the uncleaned raw data using the following procedure: 1) calculate the median Mdn_{IBI} of all N_{IBI} IBIs collected in the session. 2) convert each IBI_i into equivalent missing beat count $N_{miss}(i) = round(\frac{IBI_i}{Mdn_{IBI}} - 1)$, so when IBI_i is 1.5 times the median, it is counted as 1, if less counted as 0. If for example IBI_i

is 2.5 or 3.0 times the median, we may have missed 2 beats. $N_{miss} = \sum_i N_{miss}(i)$. 3) obtain $R_{miss} = \frac{\sum_{i=1}^{N_{IBI}} N_{miss}(i)}{\sum_{i=1}^{N_{IBI}} N_{miss} + N_{IBI}}$. The $SDNN16$ and $\overline{SDNN}$. For the calculation of SDNN, we first excluded the IBIs which $N_{miss} > 0$ and then calculated the rest of the $SDNN16$ and $\overline{SDNN}$ using the methods mentioned above. Regarding subjective measurements, the rankings and ratings in the three questionnaires were used for quantitative analysis. The comments, reasons, and reflections collected in the RRS, STAI, three questionnaires, and the post-study discussions were also used in understanding the user experiences.

6.3.2 Quantitative Results

This session describes the quantitative results in terms of our three considerations: validity of collection, readability of integration, and being stress free.

Validity of Collection The validity of the SDNN-based data collection was examined using the beat miss rate and the comparison of the SDNN calculation between our method and Kubios[2], a software for clinical HRV data analysis. In all 24(participants)×4(tasks) = 96 5-minute HRV measurements, the results of the Shapiro-Wilk test indicate that the distribution of the beat miss rate is not statistically normal ($p < 0.05$). The median of the beat miss rate is 0% and the mean beat miss rate is 0.4% ($SD = 1.3\%$). The results show the validity of the IBI data obtained from the measurement. For the $\overline{SDNN}$ calculation, the results of the Shapiro-Wilk test indicate that the distribution of differences between our method and the Kubios is not statistically normal ($p < 0.05$). The median of differences is $4.98ms$, and the mean difference is $7.53ms$ ($SD = 7.74ms$). The results show the validity of our SDNN-based stress-related data collection.

The validity of tasks was examined based on the responses to the RRS and STAI, and the SDNN calculation. Regarding the RRS, the results of a repeated measures ANOVA with a Greenhouse-Geisser correction shows that the RRS scores have an effect ($F(1.492, 34.312) = 10.341, p = 0.005 < 0.01$). Results of pairwise t-test further indicate significant differences between task 1 and 2 ($p = 0.012$), task 2 and 3 ($p = 0.02$), and 3 and 4 ($p = 0.037$). Regarding the STAI, the results of a repeated measures ANOVA with a Greenhouse-Geisser correction show that the STAI scores have an effect ($F(1.447, 33.273) = 7.880, p = 0.005 < 0.01$). Results of pairwise t-test further indicate significant differences

[2] https://www.kubios.com/

between task 1 and 2 ($p = 0.022$) and task 2 and 3 ($p = 0.004$). However, task 3 and 4 have no significant differences ($p = 0.382$), showing that the *some stressed* condition is less stressful in general. The results show that the math challenges did increase the mental stress level.

Regarding physiological stress data, we first exclude the SDNN data of 6 (out of 24) participants, who have at least one task with $> 1\%$ beat miss rate, and use the remaining 18 participants' data for understanding the effectiveness of the tasks. The $\overline{SDNN}$ is calculated using Kubios with a medium filter of artifact removal. Results of a paired t-test show significant differences in the $\overline{SDNN}$ between task 1 and 2 ($t(17) = 2.98, p = 0.008 < 0.01$), task 2 and 3 ($t(17) = -3.12, p = 0.006 < 0.01$) and between task 3 and 4 ($t(17) = 3.28, p = 0.004 < 0.01$). The results show that the relaxation and the math challenges also changed the physiological stress level.

Readability of Integration The readability of the visualization was examined based on the within-group ranking in both the calculation of $\overline{SDNN}$ calculation and the responses of "Please rank your stress level in this group based on the visualization" in questionnaires 2 and 3. Overall, the mean accuracy of $P_{SDNN+Ring}$ (83.33%) is higher than the P_{SDNN} pattern (79.16%) without a statistically significance ($p = 0.983$). If we consider one-rank error as correct, then the mean accuracy increased to 98.96% and 95.83% for $P_{SDNN+Ring}$ and P_{SDNN} respectively. The results show that participants realized the stress level within the group from the visualization. Table 2 shows the ranking results compare with the ranking based on the calculated $\overline{SDNN}$. 22 (out of 24) participants also agreed that they could see the stress level changes with time.

Mean Error (SD) of Ranking Results					
$Type\backslash Task$	1	2	3	4	Overall
$P_{SDNN+Ring}$	0.083 (0.295)	0.250 (0.442)	0.083 (0.282)	0.292 (0.588)	0.177 (0.110)
P_{SDNN}	0.250 (0.590)	0.250 (0.565)	0.167 (0.408)	0.292 (0.624)	0.240 (0.095)

Table 6.1: Mean error and standard deviation (SD) of the ranking on the SDNN+Ring and SDNN patterns.

After seeing the visualization, the users significantly changed their perspectives about their stress level regarding the group. The Pairwise t-test shows that the subjective rating in Questionnaire 1 was significantly different from the ratings in Questionnaire 2 and 3 after they saw the $P_{SDNN+Ring}$ ($p = 0.026 < 0.05$). The subjective rating is also borderline significant than the P_{SDNN} ($p = 0.069$). The subjective stress goes up when they saw the visualization, which implies people's attitudes on stress get adjusted by the visualization. The significance suggests that considering only one type of measures only shows partial stress status, which has inevitable subjective validation bias. Therefore, an additional insight of physiological signals could help the users in understanding their physiological stress and to further reflect on their subjective feelings.

Being Stress Free From a 5-point Likert-scale question during the reflection stage in questionnaires 2 and 3, the mean score of the response "You feel less stressed because the visualization is anonymous" is $M = 3.625 (SD = 0.77)$. Fifteen (out of 24) participants (strongly) agreed this anonymous visualization did not add extra pressure to themselves. The mean score of the response "I would feel more stressful if the visualization was not be anonymized" is $M = 3.625 (SD = 0.82)$. Sixteen (out of 24) participants (strongly) agreed that they might feel stressed if the visualization is not anonymized. The results showed the usefulness of anonymity during the reflection stage.

6.3.3 Qualitative Results

This section describes the qualitative results from the optional discussion at the end of the study. The descriptive conversations about the study setting, the visualization, and the reflection had been recorded, transcribed, and labeled into discrete categories using the content analysis approach [Bryman, 2016]. The results are listed as follows.

Self Reflection Individuals still make self-reflection individually, but they do the reflection with the objective data provided. Most people express the consistency between their physiological signals and their subjective feelings, for instance, "*So accurate! It exactly is the same as my personal feelings! I feel stressed when I was doing the math and especially the last task, people on my left and right were all faster than me made me feel extremely stressful*"(G1P1). On the contrary, two participants find the visualization is opposite to their subjective feelings. For example, "*I'm quite confused about the results. I meditate regularly every day. So I know how I perform when I do meditation. The measurement is the opposite with how I feel. If it is opposite, that would be perfectly accurate, because I know. I can really feel that I can make myself relax*"(G3P2). Notably, the most stressful participants always reflect on their position in the group, for example, "*I am the most stressful one! I am the most stressful one!*"(G4P3) and then either argue with the results or obsess with it and try to find the reasons behind it.

Individuals start positioning their reflection in a group context. Many are more interested in sharing their feelings and discuss with others, such as "*I'm willing to share with others.*"(G5P1) and "*That's very interesting, the program, I already start to think does anybody knows who I am. I don't mind actually sharing. Can we share? Can I tell them who I was?*"(G5P3). Nonetheless, a few people prefer to keep it as private information to themselves, for instance, "*I don't want to let everyone knows my stress level, I feel ashamed of it*"(G3P4). Also, some people mention that they would like to share if they are not the most stressful ones. "*If I'm not the most stressful one, I don't mind anonymity. But, if I am the most stressful one, I don't want it to be seen by others*"(G4P4, G5P4).

Group Reflection Participants among the group reflect on specific individual data or the group as a whole with each other. Group members reflecting on individual data indicates that people in the group get interested in exploring other people's data in their community. For example, "*It may be fun to discuss each other's stress pattern*"(G5P1). "*Oh, look, P4 is very stressed! Who is P4? P4 definitely needs a vacation!*"(G6P3). And a conversation happens in Group 1: "*A: Who was P4? B: Me! A: Oh, you're really stressed. B: I know, but I don't feel that much stressed at all. I did deep breathing during the video. I don't know why? C: Probably you're doing it in the wrong way. B: What do you mean in a wrong way? C: It is possible that stressful deep breathing would make you more stressed. Then probably normal breathing during math would perform better.*"(G1). In these quotes, group members make reflections on an individual's data and even think about relaxation interventions to help each other. Even more, some groups further reflect on the group data as a whole. Only two groups (G4 and G5) approach group-reflection on group-data. "*Are these (results) normal? Can we see other groups' data?*" (Show her the data from group 3.) "*OMG, that is so big. I feel our group performs better. The other group looks so abnormal*"(G4P2). "*What do the other groups look like?*" (Show her G3, G2 and G1) "*Wow, that looks very different!*"(G5P1). This evidence supports that the group reflects on their performance as a whole to upgrade to a new level of reflection.

Reflection on Time Some participants try to reflect on what happened during this task and how it mapped to their current stress. For example, "*The reason why I felt so relaxed was because I was tired of watching that boring (relaxation)* *video*"(G1P2); "*My last session was the most relaxed because I knew your challenge was very difficult and mine was very easy. The moment I saw my math was the addition, I felt relaxed*"(G1P4); "*I think I was still thinking about those multiplication tables in my mind, even though I actually closed my eyes during the (relaxation) video, that's why it shows up like that*"(G5P3).

Reflection on Physiological Data Some users mention that the visualization of physiological data is helpful for self-reflection, such as "*I think I know my stress level better from the visualization*"(G1P1); "*I think the insight can help me reflect on my tasks and corresponding mental stress, and modulate my own preparation and stress-handling better*"(G5P3); "*I think I prefer to compare the ring with myself, like I can see my stress change over time. I can see that during four sessions my stress is already different*"(G5P2); "*It shows that in the last task I'm not stressed. It said my stress is similar while doing the math and when I watch the video. I started wondering if my feelings not that accurate*"(G6P1). This also indicates that participants combine their physiological data with their subjective feelings for reflection.

Summary The results show that the visualization enriches the reflection, and evokes more inter- and intra-personal reflection on stress. Based on the results, the participants reflect on the data history, take other participants into account, and further share their opinions with each other.

The results show that the tasks have changed both the mental and physiological stress levels of participants with statistical significance, and the visualization has significantly changed the participants' subjective perception about their stress level. Interestingly, only 2 out of the 24 participants questioned the authority of the visualization and felt the visualization was inaccurate; on the contrary, most of the participants can make sense and reflect on the visualization to some extent. This finding is in line with Synder et al. [Snyder et al., 2015]. Although our system does provide sufficient validity, we do not wish to claim that our system is the ground truth of physiological stress. Instead, we want to highlight the fact that such an ambiguity between subjective and objective stress could be useful in engaging people in communication and therefore increase the mutual understandings among the members in the group, as discussed in [Howell et al., 2018].

6.4 Discussion

This section discusses the limitations and options for future work. We first discuss the remaining barriers of AffectiveWall using Li et al.'s five-stage Personal Informatics (PI) model [Li et al., 2010a]. Then, we discuss ethical issues such as data misuses by the employer, identity disclosure in anonymity, and the potential disclosure of HRV-related diseases. Finally, we discuss the design issues for future work to conduct longitudinal studies to understand how daily stressors affect experiences.

6.4.1 Remaining Barriers in the Five-Stage PI Model

According to the five-stage model of PI systems (i.e., *Preparation, Collection, Integration, Reflection, and Action*), problems occurring in each stage would turn into barriers that prevent users from moving on to the next stage [Li et al., 2010a]. This section outlines the limitations when collectively positioning the five stages of PI in a collective context and discusses how to address them in future work.

Preparation Stage In the preparation stage, the barrier is for the users to decide what data to track and which tool to use for tracking [Li et al., 2010a]. Our research bypassed this phase by asking the study participants to adopt our system directly. Therefore, we did not examine whether they have the intention of choosing our system as their solution. Further questions are: What data are necessary and valuable for the users? Who would benefit from this system? What could be the effective incentives that would encourage them to contribute their data to the system? These questions should be better communicated to the users.

Collection Stage Barriers in the data collection stage are mainly *user-related* or *tool-related* [Li et al., 2010a]. Regarding the *users*, in this study, we asked people to contribute their data in a short, fixed duration (one hour). As an extended time for data collection is required for a longitudinal study, future work should consider the mechanism to engage the users in contributing data continually.

Regarding the *tool*, the current implementation individually collects users' HRV data through PPG sensors via a USB wired connection, which is reliable and practical in proof-of-concept lab settings. Nonetheless, even when the study participants were well-instructed, and the study was carefully designed to allow for single-handed performing of the tasks, unconscious motion artifacts that affect the PPG signal quality were still observed. Moreover, the sensing and data collection method is still too obtrusive for the users in their everyday activities. To generalize this concept to the workplace in our daily life, the sensing method could be improved by using more unobtrusive and portable sensors, such as wearable ECG sensors [Bansal and Joshi, 2018] with a wireless data collection mechanism.

Instead of HRV, there are other objective measurements of stress [Sharma and Gedeon, 2012] that can be collectively sensed in unobtrusive and continuous ways. For instance, heart rate and breathing patterns can be measured using radar sensors [Adib et al., 2015]; voice can be measured using microphones; and facial expressions can be measured and recognized using a camera [Dinges et al., 2005]. Nonetheless, as well as the reliability issues and how strong these features relate to the participant's physiological stress, the data collection should concern social acceptance, preserving privacy and sensor deployment. These participants should be well-informed regarding these. Otherwise, these sensors may incur additional unpleasant stress for the participants even though they are unobtrusive.

In addition to the objective measurements, subjective measurements can also be collected by smartphone apps [Adams et al., 2017] or wearable self-reporting devices [Adams et al., 2018] to facilitate reflection in a later stage [Ståhl et al., 2014]. A visualization that combines both objective and subjective measures of stress can provide a more comprehensive overview for further reflections.

Integration Stage Barriers in this stage prevent users from integrating the collected social data into an understandable format that can be reflected upon [Li et al., 2010a]. The challenges of integration in the collective stress context are mainly related to *more stress-related markers*, *a longer time scale*, and *visualization for a larger group*. In this work, we use only one stress-related physiological marker (i.e. HRV) in the collective visualization. There are many other biomarkers that are related to stress, such as GSR, EEG, PD [Sharma and Gedeon, 2012]. When giving feedback with diverse types of markers, one way is to map all these stress markers to the same scale, for example, time. Another way is to use the stress index [Tarvainen et al., 2014], which is a single-value computed from several stress-related signal sources.

The current work was only deployed in the lab setting within a limited time span for engaging self-reflection in the collective context. A long-term field study to verify the efficacy of reflection in a long-term application can be explored in future work. Nonetheless, when the infrastructure enables continuous tracking, the users may require a continuous traceable history. In this case, using different shapes or spirals of different colors [Sanches et al., 2010] may be combined with users' stress along with time, to enable a clear interpretation of current and history status supporting further reflection.

The challenge for scaling the visualization to a larger group is the increasing amount of information to display. Using an interactive visualization could be a plausible solution to provide only the information of interest to the user. For example, a user can touch the AffectiveWall display to scale the timeline, browse the details, and filter unwanted information. Interaction designers should also consider incorporating seamless interaction techniques such as proxemic interactions [Greenberg et al., 2011] to provide tailored information to the target users in a more proactive way.

Reflection Stage *Short-term* reflection is valuable in bringing awareness of current status, and *long-term* reflection is valuable in identifying trends and patterns [Li et al., 2010a]. Our design aims to drive both short-term and long-term reflection in a collective context through providing a time-series data visualization. However, the test duration is not long enough to see users continuously reflecting in a longer period. Barriers in the reflection stage can be described as the difficulties in retrieving, exploring and understanding information [Li et al., 2010a]. Accordingly, the future design could proactively push data-driven insight, provide easily traceable data, and moreover, build connections between users' daily activities and data-driven insight [Ståhl et al., 2014] continuously to engage in sense-making.

In addition, another challenge when socially interpreting personal data is *privacy*. Based on the positive user feedback on the anonymity and obfuscation (avatar) mechanism, it is left for future research to test whether a privacy-preserving display outperforms a non-anonymous display and to gain more insight into the office workers' interactions. Also, participants, who were more stressed in the user study, were more reluctant to share their results with others. To preserve privacy based on the willingness of sharing, future research can also investigate and explore under which circumstances they would like to reveal [Frank, 1997] themselves or make efforts to identify others.

Action Stage Our current system has not been moved into the action stage yet, so the barriers between the reflection and action stages still exist. As with fitness tracking PI systems, the doubts regarding whether reflection helps stress management remain before the users really take remedial actions [Li et al., 2010a]. Therefore, future work can consider using the insights extracted from our study to provide actionable goals [Powers and Powers, 1973] that can engage people in taking actions to manage their stress. Providing immediate feedback on their action's progress helps to improve their sense of self-efficacy [Kersten-van Dijk et al., 2017] and to stay engaged in their behavior.

6.4.2 Data Disclosure to the Management Hierarchy

Individual workers may hesitate to contribute their physiological signals, because of the risk of allowing their personal identifying information (PII) [Schwartz and Solove, 2011] to be misused. Nonetheless, as the data is anonymized, the manager can only recognize the uneven distribution of the workload within the group, and the overall stress level of the entire group. In this way, the manager cannot identify the most (un)stressful employees. Instead, the manager reflects and adjusts the level of task loads to increase group productivity, or balance the workload among all the workers within a group. Therefore, the anonymity mechanism protects the visualized data from being misused.

6.4.3 Identity Disclosure in Anonymity

Typically, the anonymity mechanism holds its validity because no one in the system wants to disclose his or her identity to anyone who might be the most stressed and hurt one's feelings, and therefore the entire system remains anonymous in a stable state. However, the self-anonymity could be infringed if a user voluntarily discloses his or her identity to another, or anyone outside the group discloses the participant's identity (un)intentionally. In the worst case, when most of the users in the group disclose their identity to each other, the remaining one's identity could be automatically disclosed. Although we encourage the participants to share their personal feelings and situations with their colleagues, as sharing is a form of reflection that can increase people's engagement, the participants should maintain the anonymity protocol during their sharing to avoid the involuntary disclosures that harm other's feelings. Such a social protocol that avoids the self-disclosure issues should be set up and well explained to all the participants. Additionally, getting more participants involved in one visualization can also build up a more resilient anonymity mechanism that prevents the auto-disclosure problem, though the increasing scale of the visualization should be deliberately designed.

Another way to avoid the identity disclosure problem is visualizing stress-related information as an obfuscated collective without revealing personal information. However, it is unclear how individuals could engage in changing their behavior without tracing their personal information. Further investigation on providing incentives to engage the individuals in contributing to the community could be continued.

6.4.4 Health Information Disclosure through HRV

AffectiveWall only visualizes HRV, which is a physiological index that directly relates to physiological stress. It might reveal the cues of other mental disorders that are (in)directly related to HRV, but such a partial cue is often insufficient to conclude its existence (e.g., cardiovascular diseases [Lee et al., 2008]). Nonetheless, stress has been described as being associated with emotional disorders, such as anxiety [Chalmers et al., 2014, Cox et al., 2000]. Other people in the group would not distinguish the abnormal HRV from a normal stressed condition, but the person who knows that he or she has anxiety can identify his or her personal status and seek help.

6.4.5 Implications for Longitudinal Study

In our studies, we chose to apply acute stressors to the participants by asking them to perform collaborative calculation tasks. Although the applied stress is observed to have statistical significance, the nature of such a collaborative calculation task may not be representative enough of all the kinds of stressors that people experience in a naturalistic setting. A longitudinal study may uncover how the daily stressors affect coping with long-term stress. Nonetheless, valid measurements of long-term stress levels should consider the guidelines as follows: 1) Exclude the measurements under other confounding stressors, such as physical exercise, medicine intake, sickness (e.g., migraine), and other acute stressors [Altini and Amft, 2018]; 2) Create a reproducible context in how to take the measurement (e.g., PPG sensor), when to take the measurement (e.g., after wakeup, before meals), and the frequency of the measurement (e.g., three times a day); 3) Establish a statistical baseline for individuals to identify their abnormal physiological responses from the previous records. We hope our results can warrant and guide future work towards this direction of the investigation.

6.5 Conclusion

As we discussed in previous chapters, stress management triggered multidisciplinary interests and discussions. However, in the field of HCI, there is a lack of techniques and interventions for facilitating reflection of collective stress. AffectiveWall transfers the individual's vital signals into a stress index shown in a shared context, brings awareness of collective stress, and further motivates the individuals to compare their physiological signals and their subjective stress in both individual and organizational contexts in their reflection. Users can read the visualizations and change their perspectives based on the visualizations; in other words, the insights into physiological signals help the users in understanding their physiological stress and in reflecting on their subjective feelings. The visualization is also tested to be stress-free in reflection, showing that the anonymized visualization itself is not a source of stress. The qualitative results show that AffectiveWall evokes self reflection and social reflection, and improves the communication of sharing. Users consider anonymity an important issue. We also discuss the various medical and social aspects and potential barriers, which are essential before introducing such a system into practice. There still remain important questions to be answered, and both the implementation and the user studies of this article provide a solid basis for addressing these questions. It is a preliminary yet important step towards workplace stress management. In the next chapter, we will extend the time for reflection and explore how the collective stress related visualization can facilitate office workers' reflection in real workplaces.

Chapter 7

Designing for Collective Stress Reflection in the Field[1]

As described in the previous chapter, we developed AffectiveWall that evoked self reflection and social reflection. However, it is unlikely that we can transfer insights directly into stress management actions during such short-term reflection. Therefore, in this chapter, we iterate the current system with extended time for reflection to explore how it can facilitate office workers reflecting and coping with collective stress in the field.

7.1 Introduction

Nowadays, office workers often suffer from occupational stress that comes from various sources, such as job per se, role in the organization, relationships at work, or organizational structure [Jick and Payne, 1980]. In a shared working space, social stressors (e.g., peer pressure) affect the interpersonal and intrapersonal emotional status, reduce job satisfaction, and cause high absenteeism and low productivity [Cooper and Marshall, 1976, Finney et al., 2013]. Current computer-mediated interventions focus on providing stress-related physi-

[1] This chapter is based on the publication:
Xue, M., Liang, R. H., Hu, J., Yu, B., Feijs, L. (Under review). Understanding How Group Workers Reflect on Organizational Stress with a Shared, Anonymous Heart Rate Variability Data Visualization.

ological information (e.g., heart rate variability; HRV) as personal informatics (PI) [Li et al., 2010a] or as biofeedback systems [Yu et al., 2018c] to individuals to stimulate self-reflection and to facilitate self-regulation [McDuff et al., 2012, Sanches et al., 2010, Sanches et al., 2010]. They mainly use expressive and effective visualizations of physiological data as a means of communication to raise awareness and trigger further reflection and action. However, these data visualizations are often deployed on a personal display [Moraveji et al., 2012] rather than on a shared display, so the intervention most likely leverages the user's personal awareness, motivation, and skills.

Leveraging the social skills and awareness of a small group of office workers, who share the same workspace and the same task load, could further increase their mutual awareness of each other's work-related stress. Chapter 6 shows a shared, anonymous HRV data visualization can efficiently draw users' awareness and evoke objective reflections from the viewpoint of a group, but the investigation is limited as we only explored short-term reflection on the acute stressors applied to the users in a lab setting.

In the work presented in this chapter, we extend the previous work by deploying a shared physiological data visualization over an extended period: one week (5 days, 4 hours per day) in a realistic field setting. We deploy an anonymous HRV data visualization with six groups of office workers to understand how they use such visualization to reflect and to relate their daily stressors with their everyday activity in each group. We extend AffectiveWall by providing wearable and wireless HRV and motion data collection and improving the visualizations for visualizing four hours of anonymized HRV data of multiple workers, as shown in Figure 7.1. We intentionally minimize the physiological data collection apparatus and process's obtrusiveness to let the workers freely do their work in their routine. Using this system as a carrier, we invite these office workers to reflect on their subjective feelings and daily activities with their colleagues while keeping the anonymity.

This chapter aims to gain empirical understandings of how groups of office workers reflect on their collective stress with a shared HRV data visualization system. We first present an overview of related studies in Section 7.2. Then we illustrate how we extend the previous AffectiveWall system in order to support the field deployment in Section 7.3. Section 7.4 describes how we implement and test the system in the one-week field deployment. At last, we summarize the results (Section 7.5), discussions (Section 7.6) and conclusion (Section 7.7).

Figure 7.1: Exploring how group workers reflect on their daily collective stress by deploying a shared, anonymous heart-rate variability data visualization for a week (5 days, 4 hours per day) with six groups of office workers in their workspace.

7.2 Related Work

Reflection is defined as “reviewing a series of previous experiences, events, stories, etc., and putting them together in such a way as to come to a better understanding or to gain some sort of insight” [Baumer et al., 2014]. It is a complex and nebulous concept that makes its evaluation much more difficult [Baumer et al., 2014, Sumsion and Fleet, 1996]. In the theoretically-grounded reflection framework, researchers brought up five levels of reflection for design: description, reflective description, dialogic reflection, transformative reflection, critical reflection (from low to high) [Fleck and Fitzpatrick, 2010]. And questionnaires for self-reported reflection are also widely applied in reflective practice [Priddis and Rogers, 2018]. For the work in health and personal informatics, reflection plays a prominent role in *processes awareness*, *foster insight*, *increase self-control*, and *promote behaviors* [Baumer et al., 2014]. McGuire’s information processing theory claims five requirements for a message to eventually achieve action: *exposure*, *attention*, *comprehension*, *yielding*, *retention* [McGuire, 1968]. Reflection is constantly constructed during this process. Previous reflective informatics experiences suggest that only quantification is not enough. Adding qualitative data can help in understanding the complexity of reflection [Baumer, 2015]. Thus, quantitative and qualitative data are both essential in understanding reflection.

In HCI, techniques such as personal informatics (PI) and biofeedback systems are proven to be efficient in relaxation training and stress management [Kudo et al., 2014, Reiner, 2008]. Li et al. propose a stage-based model to describe PI systems in five stages: *preparation*, *collection*, *integration*, *reflection*, and *action* [Li et al., 2010a]. Biofeedback systems collect the user's bio-data (such as HRV) and provide these data back to the users in order to bring the unconscious physiological process under conscious control [Brown, 1977]. Such techniques are generally aimed at making users aware of a specific problem through self-tracking data and helping users construct insights to engage in healthy behaviors [Kersten-van Dijk et al., 2017].

Current computer-mediated interventions for stress management focus on providing stress-related physiological information (e.g., HRV [Pusenjak et al., 2015, Lee and Finkelstein, 2015]) to individuals to stimulate self-reflection and facilitate self-regulation [McDuff et al., 2012, Sanches et al., 2010]. However, little is known about how the gathered "group informatics" can be used in stress management in the workplace for facilitating the management of organizational, work-related stress. In Chapter 6, we explored how designing a physiological stress-related data visualization in a shared context can efficiently draw users' awareness and evoke objective reflections from the viewpoint of a collective. In Chapter 6, acute stressors were applied to participants by asking them to perform collaborative calculation tasks in a lab setting for short-term reflection. Such short stressors, however, may not be representative enough for real workplace stress. Moreover, the lab setting that requires each work to sit still for reliable data collection is not realistic for real working situations.

This chapter investigates how a group of workers reflect on a shared physiological stress-related data visualization over an extended period: one week (five days, four hours per day) in their workspace. We minimized the obtrusiveness of the data collection for their daily routines. As more noisy data collection was expected, we aimed to know how a group of users reflect on their stress in a less ideal yet more realistic setting and focus more on the qualitative findings than the quantitative results.

7.3 Designing Shared, Anonymous HRV Data Visualization for One-Week Field Studies

The proposed system is designed based on the design guidelines of AffectiveWall. In our previous experiments where the users experienced the induced acute stressors, AffectiveWall 1) provides valid photoplethysmography (PPG) HRV collection, 2) uses a simple yet legible mono-color round pattern for visualizing a collective of 5-min HRV data, and 3) supports a stress-free reflection through anonymity. The visualization successfully provokes group reflections on the HRV data visualization in a one-hour lab experiment. However, for a five-days, four hours per day deployment in the field, the system design has to be extended in several ways.

Portable HRV and Motion Data Collection Compared to PPG sensors, electrocardiogram (ECG)-based HRV sensing is more resilient to the wearers' body movements and the environmental light condition. Therefore, we use chest-mounted ECG heart rate sensors, Aidlab[2], for unobtrusive HRV and motion data collection. Aidlab provides an ECG-sensor that integrates a wearable computer connected ECG sensor, an inertia measurement unit (IMU), and a Bluetooth Low Energy (BLE) module. With its software development kit, timestamped raw ECG and raw IMU data from the sensors can be collected wirelessly by a Client PC. So, we can inspect the quality of ECG data collection with the raw IMU data later. Then, the Client PC processes the raw data and calculates the HRV using an algorithm based on template-matching beat extraction [Tetelepta, 2018] and then sends the HRV to a Server PC for visualization via sockets over a WiFi network, as shown in Figure 7.2.

Visualizing Four Hours of Anonymous HRV Data Instead of the circular patterns that we introduced in AffectiveWall, line charts can better represent information that changes over time. However, the line chart might be too expressive, so that could induce excess stressful feelings. To increase visibility and avoid the stressful up-and-down expressions, we use the color of grass in its lifecycle as a more biophilic expression that could generate more positive feelings [Largo-Wight et al., 2011,Wilson, 1984], as shown in Figure 7.1. We map the low HRV (SDNN$< 50ms$; more stressful) to withering color (red, orange, and yellow) and high HRV (SDNN$\geq 50ms$; less stressful) to thriving colors (from light to saturated grass green), as suggested in [Kleiger et al., 1987]. The graph gradually updates every 5 minutes, so it stays static and ambient. Notably, when the system detects insufficient heartbeats (less than 30 beats/minute on average) within the 5 minutes, the system does not over-interpret the insufficient data and shows a gap instead. The gaps may also make the wearers aware of the

[2]https://www.aidlab.com

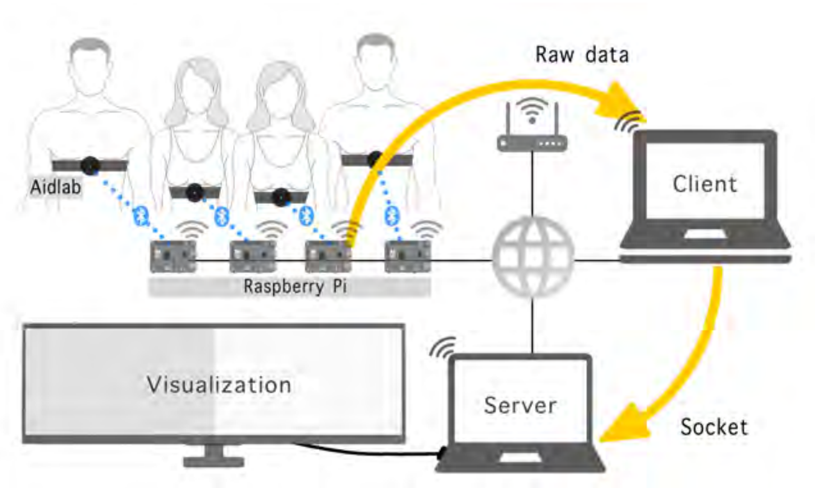


Figure 7.2: Data collection apparatus.

problems so they may ask for help. The shared display shows the color bars on a calendar-like timeline to help the users associate the bars with their daily events. The color bars of multiple users were aligned to the timeline as rows to facilitate comparison, but the display does not show participants' identities. Each user knows their row, but they do not know to whom other rows belong.

7.4 Field Study

7.4.1 Method

Participants We initially deploy the system in an office with 4 office workers for 5 days as a pilot. Afterward, we add another five groups of employees under the same settings. In total, 24 office workers (7 females, 17 males) aged from 26-49 ($M = 31.125, SD = 5.52$) were recruited from six different working groups. Five groups were employees from various research institutions, and one group worked for Information and communications technology services. Each group contained 4 employees required to be colleagues who work in the same office or are seated close to each other in a shared working space (Figure 7.1). One team leader also joined the user study.

Apparatus Four Aidlab sensors were handed out to the office workers on Monday and taken back on Friday. We used four Raspberry Pis in their office for receiving ECG and motion signals from each Aidlab sensor. An extra pressure sensor is added under each participant's seat, so the system can also annotate their leave. A laptop with a Linux system works as a Client to receive data from the Raspberry Pis. A Server laptop is connected to a shared display in their office. Every device is connected to the same WiFi network for reliable data collection.

Procedures As shown in Figure 7.3, we deployed the system for one week per group to observe how this system facilitates users' reflection and stress coping action based on both real-time and historical data within one week. Four colleagues from the same office were asked to wear the Aidlab sensor 4 hours a day (10:00-12:00, 13:00-15:00) during work for five days a week to collect ECG and motion signals to visualize. On Monday, the display was turned off as the baseline setting. It was turned on and showed the visualization from Tuesday to Friday. We choose Monday as a baseline because it is the day that is least affected by the job-related task of the previous day. We paid each participant 30 Euro as compensation.

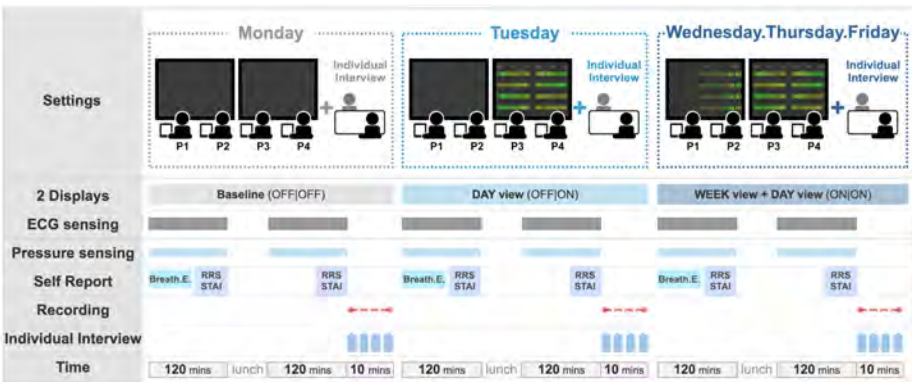


Figure 7.3: User study procedures.

We introduced the experimental protocols to the users in the daily introduction session. At the beginning of each day, the experimenter introduced to every user: what data will be collected from them, how it can be a parameter to represent physiological stress, how deep breathing can make people relax, and what the stress visualization will look like. At the end of each morning and afternoon detection, each employee was asked to fill in the self-report stress questionnaires (RRS+STAI state) [Spielberger et al., 2017]. A self-report form was also handed out to record their breathing exercise by hand as a subsidiary recording tool. At the end of each day, a semi-structured individual interview was held and recorded.

7.4.2 Measurements and Data Analysis

All the interviews were audio-recorded and transcribed according to the qualitative content analysis approach [Bryman, 2016]. The aim of our study was to gain empirical understandings of how groups of office workers reflect on their collective stress with the visualization system. In Chapter 6, we identified office workers would reflect on collective stress from the perspective of an individual or a group. Therefore, the quotes were clustered beforehand into two main categories: *individual reflections* and *social reflections*. *Individual reflections* refer to quotes comparing the individual user's subjective feelings with the visualization results (199 quotes). And *social reflections* refer to quotes comparing the individual user's stress status with others in the group (153 quotes). Two coders (one author and one external) discussed the themes and consulted our analysis approach with an outside researcher with expertise in qualitative data analysis.

7.5 Results

The First Week of Sensor Data Collection from the Field is Noisy

After conducting the study with the first group, we closely examined the 80 hours of ECG and motion sensor data collected from the 4 participants in five days. The data collection was mostly successful initially, suggesting that the system was properly deployed. However, the unstable signal-to-noise ratio accompanying loss or missing beats was detected in the middle of the collection when the users were into their workflow. From the correlation between the ECG and the motion sensor data, we identified the main cause of the noise to be the users' bodily movements. These occasionally missing/abnormal beats turned into unrealistic high HRV values that should have been processed with an advanced filter. Other events of a longer duration of missing beats occurred when the users left their seats (e.g., went to the toilet) or had a loose sensor before they adjusted it. Although the experimenter noticed missing data and helped the participants reset the device properly, the display still showed these events as gaps on the timeline. After we looked into the data retrospectively, we concluded that the quantitative data collected from the field is too noisy to be used to perform a rigorous quantitative analysis, so we focus on the qualitative results.

Users' Agreement to the System Increases with Time

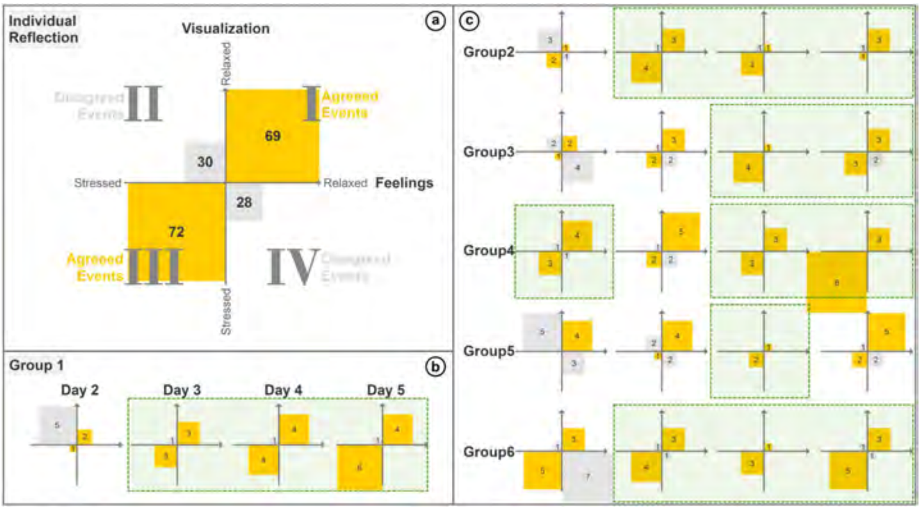


Figure 7.4: Users' agreement to the system. (a) Individual reflections related to comparisons between subjective feelings with the visualization fall into the four quadrants. (b) The frequency of agreed and disagreed events clustered from Group 1. The green boxes indicate the days with the agreement frequency 75% higher than the disagreement frequency. (c) The frequency of events for the remaining five groups.

Intriguingly, the qualitative findings showed that the users did perceive this system as a reliable system. Figure 7.4 shows our analysis of their quotes related to their agreement with the visualization. We clustered these quotes based on whether the users *agreed* or *disagreed* that the HRV visualization aligned with their subjective feelings, in both cases of stressed or not. Specifically, when a user made a statement addressing the comparisons between their subjective feelings and the visualization results, their quote was counted and categorized into one of the four quadrants:

I. The user feels relaxed; The HRV visualization shows no stress.

II. The user feels stressed, but the HRV visualization shows no stress.

III. The user feels stressed; The HRV visualization also shows stress.

IV. The user feels relaxed, but the HRV visualization shows stress.

In the first group, the ratio of *agreed* is 77.1% (27 out of 35), and *disagreed* is 22.9% (8 out of 35) among five days. More events appeared on Day 5 than the other working days because extra 30-minutes questions were asked during the exit interview on Day 5. On Day 3 and Day 5, the quotes of *agreed* are ≥ 75% among the total quotes that day. Participants showed disagreements on Day 2, the first day they saw the visualization, because the participants were expecting obvious changes (i.e., see some yellow or orange color) on the visualization at the beginning. For example, G1P1 (Group 1, Participant 1) reported, *"Sometimes I feel very stressed, but the visualization is quite green. It looked different than what I expected. (G1P1)"* Similarly, G1P2 claimed the visualization did not change much when he felt some stress near lunchtime, whereas the visualization only changed a bit within the green area. Nonetheless, on Day 3, G1P1 changed his attitudes and claimed the visualization reflect something interesting. He was watching football at that time, and his team lost the game made him upset. It surprised him that the visualization captured that moment. However, P2 still not agreed because he sensed himself stressed by the workload, but the visualization showed differently. On Day 4, G1P2 made connections with his patterns and his activities. He mentioned that he observed a gap caused by his absence. On Day 5, G1P4 showed an orange pattern for a while, which induced a group discussion. G1P4 was busy preparing some mental-demanding work while her stress showed up red. She thought the system is accurate and believed in it.

Among all the six groups, the ratio of *agreed* (70.9%) is 2.43 times higher than *disagreed* (29.1%). Like Group 1, we also found the other five groups showed an increased agreement from day 3. Figure 7.4 highlights the days when *agreed* is ≥ 75% of the total, which are considered that the group of four participants generally agreed on the visualization. We interpret this finding as that the users who used the visualization calibrated their subjective feelings and the expectation of systems with time.

We further analyze the daily events to understand what were the drivers of change. The participants in Group 1 and Group 4 perceived the visualization changes aligned with the changes of tasks at hand. For example, *"It's accurate, I noticed it's related to the intensity of my current task. I noticed the change, I paid some attention in the background, and I would do something when I got time"(G1P4D5)*[3]*. "It must be mood-related. I felt good because I received some exciting news this morning, I was in a very good mood, and I saw a red bar. I think it senses my excitement as well"(G4P3D5). "I usually make a phone call to my home in the afternoon. Sometimes when I check the time, I'm stressed because I need to finish all the tasks at hand before they go to bed. And my bar was getting yellow at this period. After I finished the call and went back, it went back to green"(G4P2D5).* Group 5 has relatively fewer quotes on Day 4 than the other days because the system detected no specific event on that day (no one got stressed); also, one of the group members had to work outside of the building, which made the reflection material even less.

When users' subjective perceptions aligned with the system's feedback, they were more willing to engage further and interpret their data. For example, the system captured a participant's emotional event. Then, she expressed her interpretations of the visualization in the interview: *"I'm very surprised it can catch my exciting moment, the change with my heart. I guess I get the point. It doesn't exactly represent stress all the time. It reflects the mood"(G4P3D5).* Nonetheless, if the system provides unmatched data with users' expectations, it would destroy users' trust in the system. For example, one participant (G6P4D2) claimed he was a relaxed person by nature, and all his colleagues expect he must be the most relaxed person of all. However, he turned out to be the most stressed one. Therefore, he claimed he does not believe the data provided: *"I think I should be P2 (the greenest one in this group). It doesn't match my feelings. I don't know whether the data has deviation."* Another example from Group 2, P1 claimed she had a few episodes on Day 5 because of some chaos she couldn't handle at work, *"...not burnout, but at least I had some bad emotions come and go. But the visualization stays green. That does not match."*

Social Reflections: Group Workers Compared with Peers and Shared the Stress-Coping Strategies

Office workers not only compared their subjective feelings with their own physiological signal visualization but also compared with each other in light of the

[3] Group1-Participant4-Day5

visualization. Following the same approach in individual reflections, we cluster the quotes of *social reflections* into four quadrants as shown in Figure 7.5a.

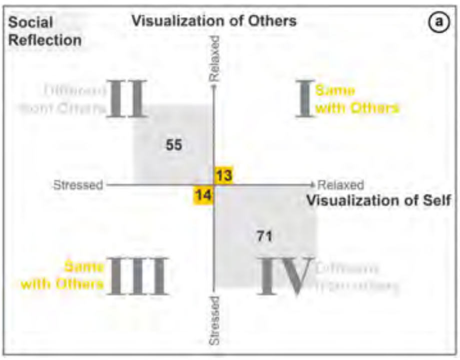
I. The visualization shows both the user and their peers are not stressed.

II. The visualization shows the user is stressed, but their peers are not.

III. The visualization shows both the user and their peers are stressed.

IV. The visualization shows the user is not stressed, but their peers are.

The quotes were then categorized into two categories: *Same with others* (I and III) and *Different from others* (II and IV). The daily quote amounts of the two categories were compared in Figure 7.5b, in which we highlighted days that the participants ≥ 75% agreed with the system (as in Figure 7.4b-c) with at least 3 quotes in total.



(b)

	Day2		Day3		Day4		Day5	
	same	diff	same	diff	same	diff	same	diff
G1	2	3	1	1	2	1	3	16
G2	0	5	0	0	0	1	3	8
G3	0	7	0	1	1	2	1	11
G4	1	6	0	1	1	2	3	10
G5	1	7	0	4	0	1	2	18
G6	0	6	0	2	0	0	4	13

Figure 7.5: (a) Social reflections related to comparisons of personal stress with peers. (b) The table of frequency on the "same events" and the "different events" along four days of use. The green boxes indicate the days that users agreed with the system, meanwhile, the daily response events are higher than 3.

More discussions were found when users realized the differences with peers than under the same status. The quotes of *Different from others* (82.4%) are 4.67 times more than *Same with others* (17.6%), which indicated that users made more comparison statements about their differences when someone shows stressed performance on the visualization. When the visualization showed someone is getting stressed with a bar of continuous yellow or orange, office workers made quotes on *Social reflections* 10.77 times higher than nobody showed up stressed. For instance, *"I did not realize that mine gets red until my colleague asked me"(G1P4D5). "I was a bit worried that I had no yellow at all, everyone else has somewhat yellow parts, only me was all green"(G3P2D2). "Compared with other colleagues, I am the most stable green one"(G5P1D2). "The whole afternoon shows yellow, more yellow than each of them"(G6P1D3)*. These findings showed office workers also use the physiological data visualization from peers as a reference to understand self through comparisons, especially when there is a difference or someone is stressed. Participants shared their awareness of each other's stress and stress management methods with people within the group. People co-interpret the visualization through discussions during small breaks throughout the day. For example, after every member in Group 4 has self-disclosed their identity, they interpret the visualization together during the breaks. For instance, *"Before it happened, the four of us discussed what we saw was the three of us appeared to be in the same shade of green, but only his bar had some fluctuations. We discussed possible reasons for that"(G3P2D4)*. They discussed the possible reasons for their stress, *"We found everyone's stress is different because of the differences in stressors through our conversation today, and it's not necessarily from work only"(G3P2D2)*. And participants propose new ways of coping with the stress together, *"If your colleagues know that they will try to help you to get over it"(G5P3D5); "We can release the stress through taking group breaks and making jokes together if we know we are stressed"(G6P1D5)*.

Overall User Experiences

We also asked how users' experienced this visualization during the exit interview. We asked the questions individually (e.g., Was the information clear to catch from the visualization? Was it interrupting your work? What were your opinions on anonymity? What were your opinions on the design?). We transcribed and analyzed their answers from all the six groups of office workers. The results indicate that the visualization information was easy to perceive, clear to understand, and was not interrupting in general. All participants reported that the color design matched their intuitions, and the information was easy to catch. "*It's very easy to understand, I mean, there are quite a lot of things use this, red is bad, and green is good"(G5P1D5). "Green is always good, if you go far away from green, like yellow, to red, almost everywhere, it's not a good sign [...] for me it was clear" (G6P3D5).*

22 (out of 24) participants reported the visualization was not interrupting their work. 2 (out of 24) claimed that they could not stop watching the changes in the beginning, and it was to some extent distracting. For example, *"All morn-*

ing I was watching very often to the bar, keep me sharp that how I was on my mind and how stressed I was or not. I kept watching" (G5P1D2). 21 (out of 24) participants reported that they were engaged to take actions to manage stress from the visualization. 2 (out of 24) participants claimed their performance was so well; otherwise, they would be engaged in doing something if their bar showed up red. 1 (out of 24) participant (G6P4) was not engaged in doing anything because he did not believe the delivered information. 22 (out of 24) participants reported they did not mind sharing personal identity with their colleagues. A majority of them expressed they were willing to share because of the closeness or familiarity with peers.

We found various attitudes on sharing. Some group wanted the system with all group members' names on the visualization. For example, all members from Group 5 would love to see their names on the visualization, including the team leader G5P2: *"From a team leader position, I actually do prefer seeing that because you can see which colleague might not able to cope with stress and you could probably help them, prevent them from getting more stressed or making mistakes. I can always do something when this situation comes up. See which colleagues might not be able to continue on, which ones might be tired"(G5P2D5).* Some group didn't care whether the system was anonymous because they had a relatively open and close relationship with their colleagues. For example, *"If I share this with strangers, I would prefer it to be anonymized because I would rather worry others see my stress and treat me as a patient. But I have already worked with my colleagues for more than four years, and we already familiar with each other, so it's no problem to share with them"(G3P1D5).* One group (Group 4) held different opinions as they were the only group that followed and kept the anonymity rules till the end of the study. One participant in that group claimed he was new there and felt awkward sharing with colleagues. He thought of stress as something private: *"Luckily, we do not have that much stress made people want to talk and guess. I think anonymity can protect those who don't want to share. If it's not anonymous, it will bring more stress"(G4P1D5).* And his colleague added she followed the rules of not sharing with others: *"Till the end, nobody knows who I am, and I only know P4 because he went away for a long time and expose himself. I didn't say a thing (to expose him)"(G4P3D5).* But not all the members in that group felt the same about anonymity. For instance, G4P2 and G4P4 talked with each other and exposed themselves: *"I was eager to know why they feel stressed, even though I may not be able to help"(G4P2D5).*

7.6 Discussion

In this section, we discuss the design implications, limitations, and options for future work.

Reflection as Dialogues with the System and the Peers Stress is a subjective feeling. Physiological data such as HRV are considered as stress indicators rather than a basis for a clinical diagnosis. The users should use the HRV data visualization system as a reminder to reflect on their feelings and their experiences instead of taking the HRV visualization as a stress meter. Designers should encourage users to observe the differences between physiological data and their subjective feelings to make sense of the two's differences. In a group, the users can further learn from their peers' ways of interpretation and their preconceived impressions (e.g., my colleagues think I'm a relaxed person). It aligned with Höök et al.'s concept of *Affective loop experiences*, which describes experiences "where it is not possible to separate the intellectual from sensual experiences, nor to single out what is my individual experience from the overall experience arising in dialogue with a friend or in dialogue with a system" [Höök et al., 2008].

Sharing is Caring Although this research was limited by the nature of subjective interpretation and the imperfect data collection, these did not prevent the participants from interpreting the HRV data visualization. Conversely, the participants increasingly agreed with this communication medium and engaged in discussion with their peers. One possible reason is that one can hardly evaluate the accuracy of the system's objective feedback by heart, as one is often not so sure about one's subjective feeling. The way how the users agreed with the system may consist of confirmation bias. Still, those willing to share their feelings and co-reflect with others also benefited from others' awareness and caring. As a result, they got more peer supports than those who don't trust the system and refused to interpret.

Data Transparency Although the physiological sensing system was perceived as sufficiently reliable to be used as a reflection tool, designers should still strive to provide accurate physiological measurements in the field. Nonetheless, noises and errors are almost inevitable because there is less control over the experiment in field settings. As suggested by Jaimes et al. [Jaimes et al., 2013], designers should provide users with two forms of transparency: data acquisition transparency and data uncertainty transparency to ground the users' expectations. In our current system, data acquisition transparency is embodied as the gaps of missing data in the bars, which let the users believe that the data collection did work. However, our system could improve the data uncertainty transparency by showing how reliable the HRV data is in real-time rather than marking high-HRV motion artifacts as no-stress. With higher transparency, the users can understand what kinds of errors could be in the data and to what extent they can trust the data [Jaimes et al., 2013].

Peer Comparisons Users realize the interpersonal differences mostly through comparisons. It implied that emphasizing the interpersonal comparisons in visualization design might engage social sensemaking among peers. However, the comparison is a double-edged sword that implies both benefits and risks and thereby needs to be carefully designed for [Valkanova et al., 2013]. On the one hand, peer comparison can sometimes be stressful and burdensome, for example, if one is left behind. On the other hand, implying the overall performance of a team can motivate the members to achieve more. Fairness is the basis of comparison. To avoid comparing apples and oranges, the system is the most applicable for users with similar conditions, such as people from the same level in the hierarchy or who share similar stressors. For example, in the context of mobility-impairment users' activity tracking, participants show a great desire to compare with peers with similar mobility impairments to discover new possibilities in rehabilitation [Malu and Findlater, 2017]. When the situations are relatively comparable, the comparisons in shared experiences would be meaningful.

Future Work Based on our results, future work can explore how to customize anonymity of sharing, such as allowing the individuals for self-identity disclosure in a subgroup because people have different preferences of sharing their stress. Future work can examine how participant closeness (e.g., how long they know each other, level of familiarity, or subjective closeness of relationship [Gächter et al., 2015]) would affect the stress sharing experiences and how closeness could complement our research in users' privacy concerns. Future work can generalize this HRV visualization for other contexts, such as group sleep tracking [Pina et al., 2020], to understand the potential socio-technical issues in new applications.

7.7 Conclusion

In this chapter, we present an empirical study of how groups of office workers reflect on their collective stress with a shared HRV data visualization system in the field. The extracted qualitative results show the group of users take the deployed HRV data visualization system as a carrier to share their awareness and intervention with their peers. The one-week field deployment indicates that the presented system is able to engage its users to make meaningful reflections related to the stressful moments they have in their daily activities. The results extend from previous works by showing the applicability of shared anonymous HRV data in the field and contribute valuable insights into future longitudinal studies. In the next chapter, we will focus on discovering the application scenarios based on office workers' authentic working experiences.

Chapter 8

Developing the Application Scenarios[1]

Chapter 7 presented a one-week field deployment of an extended AffectiveWall system. The deployed system raised group awareness, facilitated social reflection, and constructed increasing trust to assist participants' subjective stress assessment in our one-week observation. However, in-depth understandings of users' needs and envisaged scenarios based on their authentic experiences are still lacking. To address this opportunity, we utilize a participatory design approach called co-constructing stories to investigate how a collective stress visualization would be used in office workers' authentic workaday routines. We construct use case stories together with a group of office workers based on their lived experiences, using a design probe called AffectiveGarden. The results yield a rich categorization of insights that users expect to gain from the visualization, and six clusters of envisaged benefits in facilitating collective coping are identified. These clusters are generalized as desirable design qualities for future collective stress visualization systems. Moreover, we summarize the motivating factors and concerns for users to share their stress data, with a nuanced view on whom to share with. We discuss the implications from the rich co-constructed contextual data to inform future design practice.

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[1] This chapter is based on the publication:
Xue, M., An, P., Liang, R. H., Guo, Z., Hu, J., Feijs, L. (Under review). Co-constructing Stories Based on Users Lived Experiences to Investigate Visualization Design for Collective Stress Management.

8.1 Introduction

Collective stress exists when the "members of a particular organizational culture as a group perceive a certain event as stressful" [Lansisalmi et al., 2000b]. Excessive stress in the workplace affects the individual's psychological and physiological health [Kivimäki et al., 2006], reduces working performance, and leads to poor communication and increased conflict [Michie, 2002, Rodríguez et al., 2019]. The problem of too much collective stress is to be solved both for individuals and for organizations. Coping with stress should involve the interpersonal social facets because it is not just a process inside the individual, but often "takes place in dialogue with others" [Kirkegaard and Brinkmann, 2015]. Moreover, social coping is proved to be more efficient in reducing employee stress than individual coping [Rodríguez et al., 2019]. Hence, previous social-psychological studies imply the need for developing group intervention tools to facilitate social coping with stress.

With the aid of Human-Computer Interaction (HCI) systems, users could be provided with actionable, data-driven self-insights to help them optimize their behavioral patterns and thereby improve their well-being [Kersten-van Dijk et al., 2017, Li et al., 2010a]. Current HCI approaches, such as biofeedback interventions [Yu et al., 2018c] and personal informatics (PI) systems [Adams et al., 2014, Lee et al., 2020] have been widely applied in stress management for individuals. In our previous approaches, we used PI collectively to raise awareness of collective stress for office workers. For example, AffectiveWall [Xue et al., 2019] adopted a PI approach to anonymously visualize stress-related physiological information for a group of office workers in order to raise awareness, facilitate reflection, and stimulate stress-coping action. Such systems increased office workers' individual reflection as well as the social reflection on stress status, and could trigger stress-coping action (e.g., take deep breathing exercises) when office workers relate their subjective stress to the stress-related data (e.g., Heart Rate Variability) visualization. However, the limitations in real-life sensing and the short-term user tests in controlled settings can be a hinder in gaining in-depth, authentic stories about how such a system would be used in users' natural settings. And these stories are crucial input information for future designers.

To get access to these stories, nevertheless, we adopted a participatory design approach in order to gather in-depth understandings and thus inform the future design practice of collective stress visualization. Specifically, we utilized the co-constructing stories method [Buskermolen and Terken, 2012] to elicit in-depth user responses and visions based on their lived experiences in workaday

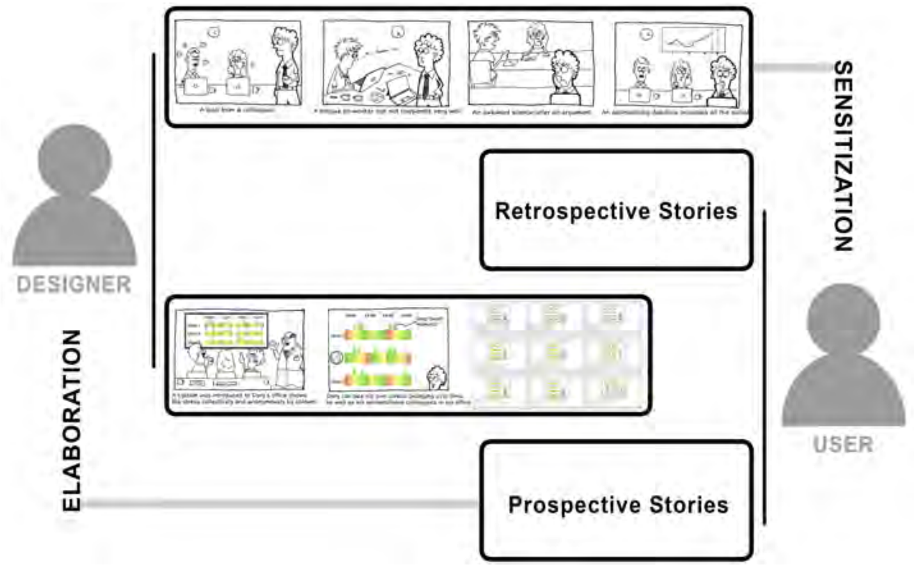


Figure 8.1: The method of co-constructing stories contains two phases: sensitization and elaboration [Buskermolen and Terken, 2012]. We use storyboards to evoke user's past memories and introduce AffectiveGarden as a visioned future to elicit feedback.

routines. First, we created ready-made narratives for office workers to relate to their past experiences on collective stress and trigger them to articulate their expectations on how collective stress visualization would be implemented in their real life. Then, we introduced a design concept (AffectiveGarden) as an anticipated future to evaluate fictional scenarios based on their own context (see Figure 8.1). To adequately sensitize participants about various types of group performances, we showed several narrative storyboards with different group performances. In the end, we conducted in-depth interviews separately with 12 office workers from different professions, and 771-minute audio recordings were transcribed and analyzed using thematic analysis [Braun and Clarke, 2006].

Section 8.4 shows a rich categorization of insights that users expect to gain from the visualization. We conclude six preferred design qualities of collective stress visualization systems. The results also indicate the factors that may engage office workers to share their stress data as well as the roles in the workplaces they would like to share with. As a result, this chapter reveals the potential opportunities of collective stress visualizations via co-constructed authentic usage scenarios, which translates users' needs and desires into design implications for future research and practice.

8.2 Related Work

8.2.1 HCI for Stress Management

Stress management is a process from recognizing the stressors to taking actions to cope with them. Aligned with the transtheoretical model (TTM) of health behavior change [Prochaska and Velicer, 1997], HCI researchers developed systems to facilitate this process. Stress management in HCI often relies on biofeedback systems and Personal informatics (PI) systems to enable individuals to be aware of their physiological activities for self-insight and self-regulation [Brown, 1977]. HRV is often used as one of the physiological stress parameters [Sharma and Gedeon, 2012, Dimitriev et al., 2008, Kang et al., 2004]. HRV can be collected through wearable sensing devices and then get processed and presented to the users through visual [Henriques et al., 2011, Feijs and Delbressine, 2017], auditory [Bhandari et al., 2015], and tactile [Weffers, 2010] modalities for relaxation training and stress management. For example, breathing-based biofeedback systems guide users to make six-per-minute slow breathing patterns that are proven to be effective in elevating HRV and mediating physiological stress [Brown and Gerbarg, 2005, Gevirtz, 2013a].

8.2.2 Collective Stress Interventions

With the existing theories [Schein, 1996] in organizational psychology and sociology, related literature views stress as a cultural phenomenon that is distributed socially [Kirkegaard and Brinkmann, 2016]. And researchers increasingly place emphasis on "the collective nature of stress experiences and coping" from an integrated view [Lansisalmi et al., 2000b]. Current research points out the need to cope with stress beyond the individuals and explore stress management in teams and organizations, because social coping is more efficient in reducing employees' stress [Rodríguez et al., 2019]. Interventions on collective stress are only sporadically reported in the social psychology field [Folkman and Lazarus, 1984, Lansisalmi et al., 2000b, Rodríguez et al., 2019], which implies an unaddressed opportunity for HCI research to develop tools to facilitate collective coping.

HCI interventions for stress management are mainly designed for individual users [Kocielnik et al., 2013, Sanches et al., 2010]. Since social influences are considered to be a significant positive factor in promoting healthy behavior change, more and more self-revelation systems start to incorporate social features [Li, 2009, Sundström et al., 2009]. For example, Miro [Boehner et al., 2003] visualized the office emotional climate through a dynamic public painting. It probed into visualizing affective information in a social context for drawing wider consciousness. But Miro's ambiguous representation obstructed audiences from understanding the information. MindFocaster [Lee et al., 2020] was designed as a calendar-mediated stress anticipation application that allowed users to expect stressful events in advance and to generate plans to mitigate the stress. The "peer" mode of MindFocaster allowed users to see stress interventions shared by fellow participants. However, users had to enter the events and assess their stress levels repeatedly for data collection. In our previous approaches, AffectiveWall [Xue et al., 2019] was developed as a shared visualization that shows office workers' physiological stress indices (HRV data) anonymously in the social context to raise awareness of organizational stress. The user studies showed that AffectiveWall increased group members' individual- and social- reflections in both lab and field settings, which could stimulate collective stress regulation. However, the current sensing limitations and the short-term deployment can be a hinder in gathering in-depth, authentic stories about how such a system would be used in real situations, and what the users' latent needs and expectations are. Those stories are essential contextual information for informing future designs.

8.3 Research Probe: The AffectiveGarden System

AffectiveGarden is an ambient stress-related informatics system that shows the office workers their physiological stress-related signals and deep breathing moments in real-time anonymously on a shared display in the office. Since physiological stress is related to HRV [Sharma and Gedeon, 2012, Dimitriev et al., 2008, Kang et al., 2004], our design probe collects the group's HRV to visualizes them in an intuitive way to facilitate group reflection on collective stress. The group members' physiological stress (HRV index) is collected and analyzed individually through a wearable sensor and visualized with colored bars. Stress is mapped to withering color (orange), and relaxation is mapped to thriving color (green). Deep breathing can be detected through the embedded accelerometer [Hung et al., 2008]. When the system spots a continuous deep breathing pattern from the user, grass will sprout at that moment on his or her time-line bar as a kind of trophies toward stress management. Office workers can see their stress changing over time, as well as that of their unidentifiable colleagues.

In this study, AffectiveGarden was presented as a probe to evoke office workers' contextualized visions based on their lived experiences, using co-constructing stories [Buskermolen and Terken, 2012]. We made storyboards to present the AffectiveGarden as an open-ended design concept instead of a finished prototype, to stimulate users' imaginations and visions. In this way, users can freely express their latent desires and tacit needs by participating in constructing the stories of use scenarios based on their past experiences.

8.3.1 Participants

Table 8.1: Demographic Information of Participants

Age	Gender	Nationality	Occupation
27	Female	Dutch	Office manager
35	Female	Jamaican	English teacher
54	Female	Dutch	Congress organizer & associate manager
27	Female	Dutch	Consultant in education in youth care
29	Male	Indian	Process engineer
35	Female	Jamaican	Content curator
25	Male	Greek	Analyst
27	Female	Dutch	Finance staff
28	Male	Australian	Process engineering
29	Male	Indian	Accountant for an IT company
26	Female	Canadian	Secretary
35	Male	Japanese	Sales & product designer

In total, 12 office workers (7 females, 5 males) aged from 25 to 54 years old (M = 31.42, SD = 7.98) from different professions were recruited. The demographic information of the participants can be seen in Table 8.1. All participants were: 1) healthy adults; 2) employees who share an office with 3-15 coworkers; 3) not under-recovery of burnout and did not have a burnout history; 4) fluent in the English language. Participants were recruited using snowball sampling [Patton, 1990]: a few individuals who met the eligibility criteria were selected initially, and they were asked to help us recruit other potentially eligible participants [Creswell and Poth, 2016]. Then we made appointments with the potential participants to confirm whether they were qualified candidates for participating in the study. We estimated the sample size to be between 10 and 20, which should be a suitable range to gather rich and in-depth qualitative insights, and meanwhile avoid excessively repetitive responses, or over-saturated data. Ultimately, 12 participants were recruited in this study.

The study was approved by the local Ethical Review Board (ERB) from the Industrial Design department, Eindhoven University of Technology. The study involved users' visions on how they would experience such a system in their real-life workplace, which may risk triggering their stressed past experiences. To avoid burnout or causing unwanted feelings, users were informed in the consent form that they could stop participation at any time. And they could withdraw the permission to use their data in any condition. The study paid each participant a 5-Euro voucher as compensation.

8.3.2 Co-constructing Stories

Co-constructing stories is a participatory design technique to elicit users' in-depth feedback and suggestions about the design concept [Buskermolen and Terken, 2012]. It is based on the assumption that "users can make better judgments about the future design concepts if they link them to their past experiences" [Buskermolen and Terken, 2012]. The co-constructing stories method contains two phases: sensitizing users' past memories on the topic of interest and elaborating the design scenarios to evoke their expectations and needs for future applications. The whole process is established through collaborative storytelling, where the designer sets a stage for dialogue.

Sensitization Phase

In the *sensitization* phase, we started with a fictional story through sketching (Figure 8.2) to introduce a couple of collective stress scenarios in order to evoke participant's past experiences on collective stress. The designer started the narrative by presenting four typical social stressors that occurred on the main character Dory: colleagues sigh a lot, colleagues cannot collaborate very well, quarrels make the atmosphere very awkward, approaching deadlines occupy office workers' social time. The story ended by asking the participant whether they had been in similar situations and which aspects of the story made the situation recognizable for them to relate to their past experiences. Afterward, each participant will be asked to recall the three most salient times that he or she had experienced in their real-life and how the collective stress situation continued in their case. This way, throughout the sensitization phase, we were able to obtain a deeper understanding of participants' context of use.

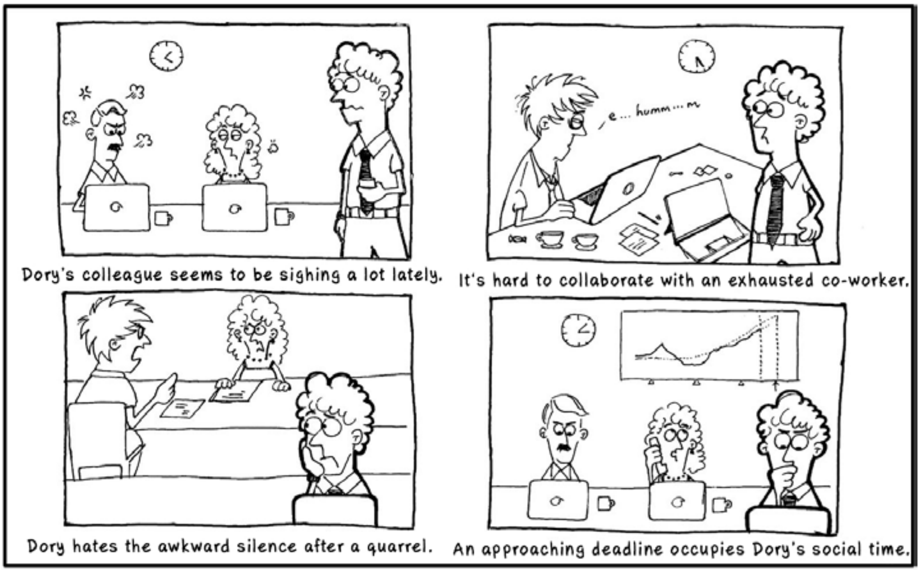


Figure 8.2: In the *sensitization* phase, a fictional story was told by the designer in order to evoke participants' past experiences on collective stress.

Expectation Phase

Following the aforementioned story, we set an additional phase between sensitization and elaboration with questions regarding office workers' expectations. We illustrated example solutions to collective stress to explore participants' expectations of visual expressions (Figure 8.3). By restricting the design on visual solutions, we are able to invite participants to co-design based on existing knowledge of our previous visual explorations in the field and meanwhile release the participants' pressure to come up with brand new solutions in a short time. We named this additional stage as *expectation* phase. We continued Dory's story and illustrated how the human body reacted to stress, how stress can be accurately measured, and ended up with collective stress visualization that can help. Then we asked participants what they expected to see in the visualization and let them co-design scenarios on how such visualization could help group members manage stress.

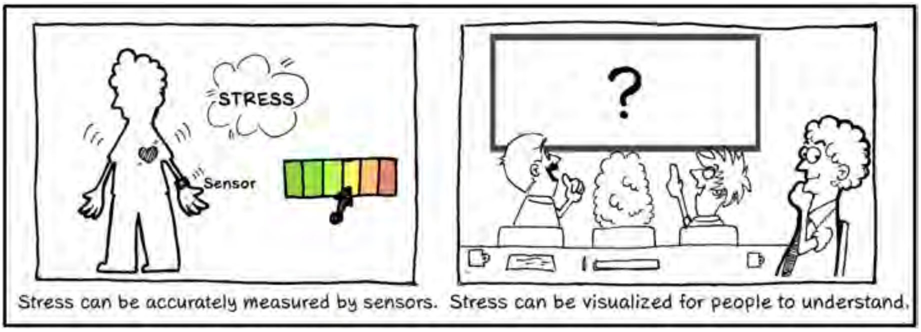


Figure 8.3: In the *expectation* phase, we continued Dory's story to understand participants' expectations on the collective stress visualization design.

Elaboration Phase

In succession, in the *elaboration* phase, we introduced AffectiveGarden in a visioned context and illustrated the concept through sketching (Figure 8.4). Specifically, in the last part of the story, we first illustrated Dory and his colleagues' scenario in the use of AffectiveGarden in their office (Figure 8.4a). Then we explained how the AffectiveGarden system worked (Figure 8.4b) and how Dory and his colleagues interacted with it to cope with collective stress (Figure 8.4c).

After the story ended, we asked the participants to illustrate what they like and dislike about the AffectiveGarden design to elicit their positive and negative feedback. And we asked them to think aloud and envision how the story would be like if they are the main character. What would they do, and what would stop them from coping with stress through interacting with the visualization? And we encouraged the participants to link their previously-described past memories with the AffectiveGarden design concept, to let them elaborate on how the design could be adapted or applied in their own context. The situations in which they prefer to use such a system are also collected.

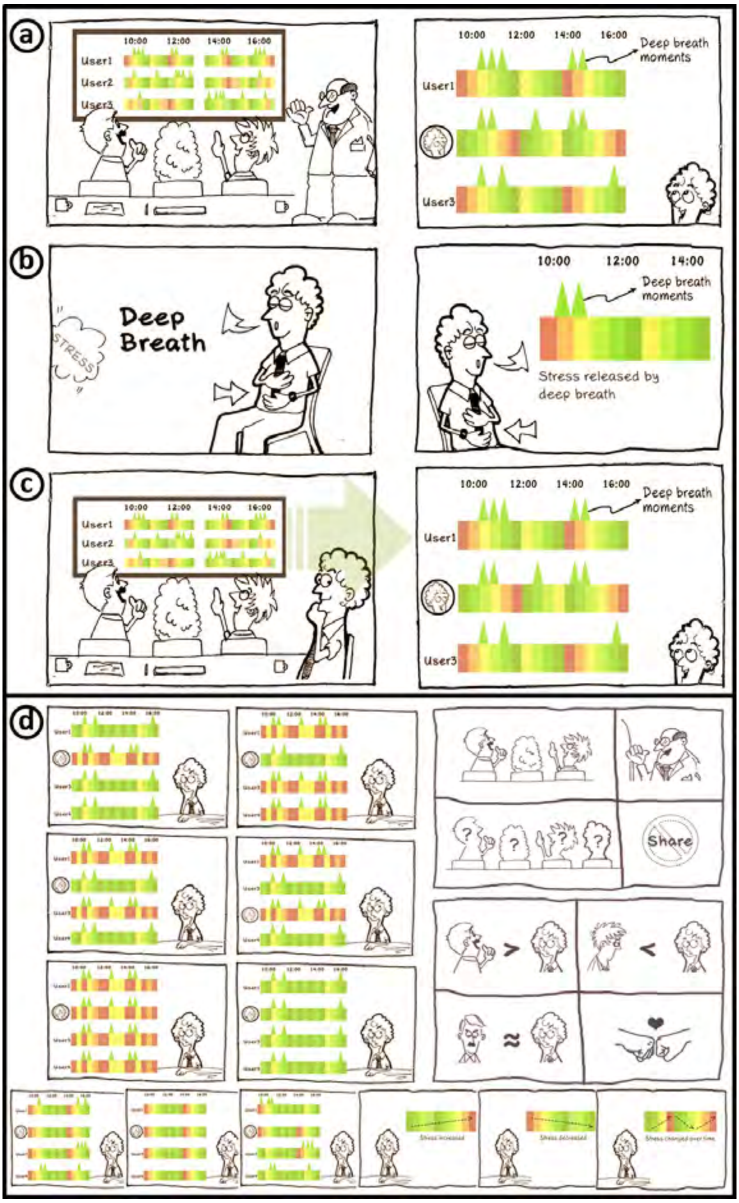


Figure 8.4: In the *elaboration* phase, the story illustrated an anticipated future to apply AffectiveGarden in an office scenario. The participants were engaged in finishing the story according to their own needs, dreams, and aspirations.

Afterward, to adequately elicit the users' feedback about various group stress levels of the collective stress visualization, we show the narrative storyboards with different group performance. Various situations are presented, such as the participant is the most stressed one; or the participant is the most relaxed one; or the participant is stressed but not alone; or the participant is in a situation that everyone is stressed, and so on (Figure 8.4d). The dialogue also included participants' willingness to share their stress information and whom they would like to share with.

8.3.3 Analysis

We transcribed the interview recordings that covered the whole storytelling session. In total, there were 771-minute of data from all the participants; each in-depth interview lasted for approximately one hour. We conducted the inductive thematic analysis method [Braun and Clarke, 2006] to identify office workers' contexts, expectations, as well as attitudes on the usage of collective stress visualization design. These aspects formed our main analytic interests. The process of data analysis followed the six phases in [Braun and Clarke, 2006]: familiarising with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, producing the report.

8.4 Results

All participants were sensitized to relate their past experiences with the collective stress scenarios, and this led to rich experiential data that helped us understand this design context. Corresponding to the example scenarios provided to them (such as 'arguments with colleagues' or 'the approaching deadline'), the participants were able to recall similar types of scenarios from their own experiences. Furthermore, some participants added examples from new kinds of collective stressors (such as colleagues tapping their feet all the time, or anxiety of others). By analyzing these co-constructed authentic narratives, in this section, we report the findings in regard to our two-fold research questions: (1) how a collective stress visualization could impact collective stress management; and (2) the motivating factors for sharing stress information as well as to whom people would like to share (and why). At last, we summarized users' concerns in deploying such visualization systems in their workplaces.

8.4.1 How Could A Visualization Design Impact Collective Stress Management?

In this section, we answer this question by summarizing *the types of insights that users can learn from a collective stress visualization* and *what impacts these insights would lead to*. These impacts are then generalized as six preferred design qualities from users' visioned scenarios for collective stress management: reflection and reasoning, self regulation, empathic concerns, reciprocal help, constructive conversations, and collective coping measures (see Figure 8.5). Below we will first address the types of insights expected by the users, and then connect these insights to their impacts.

Insights into My Own Stress Status

When they saw their own stress data, the users would tend to reflect on where that stress status came from. And they would try to mitigate their stress status after being aware of it, either by doing self-regulation or requesting help from others. As reported by P3, if she could see her stress level changing over time, she would firstly reflect on *"what the situations are, and why you are stressed."* And this could make her *"be more relaxed about the situation with stress"* because she will be more aware of what happened and thus have more conscious control over *"what to do with it."* For another example, P4 claimed that with insights into her own stress level, she would *"first try to manage"* by herself before asking help from others. If the stress status remains after self-regulation, the participants mentioned that they would ask for help from others. For instance, P2 noted, *"I would tell them the challenges that I'm having, and ask for help. Am I wrong? Am I right? What is your advice?"* In sum, these examples indicated that the insights into one's own stress status are essential for users to gain understandings about themselves and to motivate stress-coping activities, including self-regulation or requesting help.

Insights into Others' Stress Status

The participants mentioned that being more aware of their colleagues' stress levels would make them be more considerate and do things differently. And they could have more empathy for colleagues and more willingness to understand others or to offer help. First, the participants said they would like to reflect and speculate on the possible reasons that might cause others' stress levels to rise. P4 compared a stress situation to climbing a hill, she noted if she

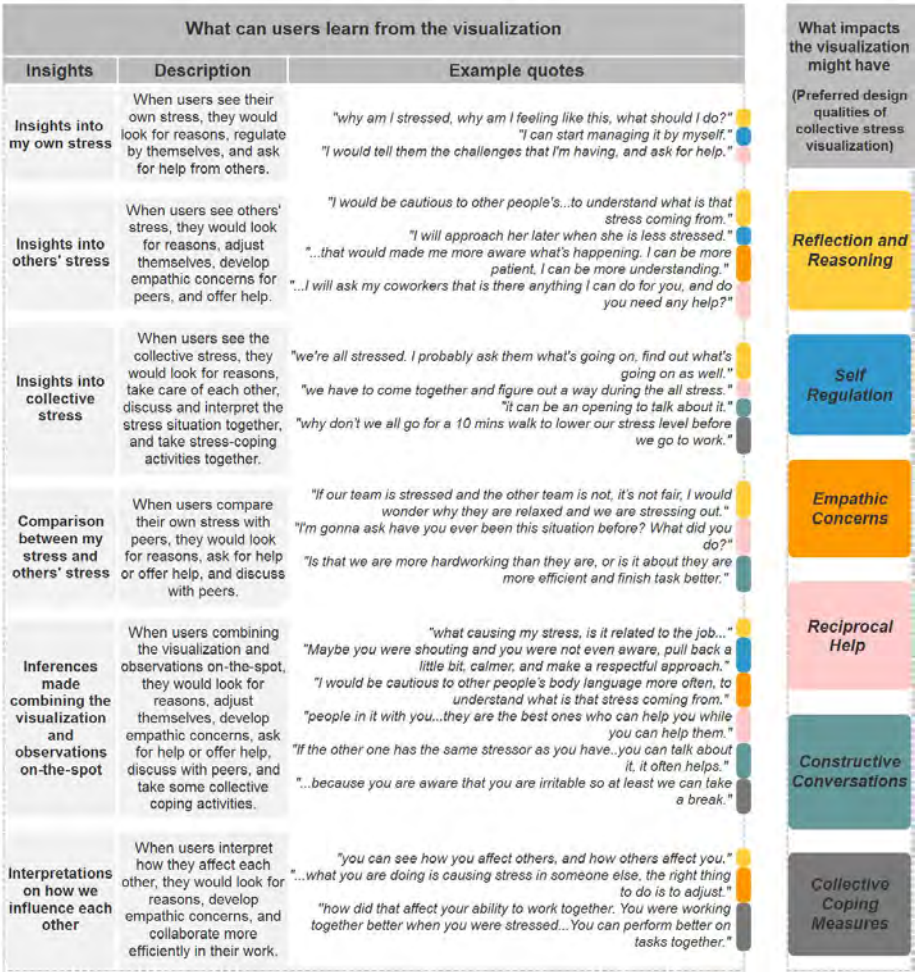


Figure 8.5: To understand how the collective stress visualization could facilitate collective stress coping, we make connections between *what users can learn from the visualization* and *what impacts the visualization might have*. The six preferred design qualities construct our framework of collective stress intervention design.

saw her colleague always at the top, she would let him become aware and figure out why: *"Is it a work situation or a private situation?"* Second, seeing others' stress-related information makes people adjust their behaviors, and do things more thoughtfully according to the current situation, and contributes to a harmonious working environment. For instance, P1 mentioned: *"if I know that you are very stressed that day, then I think, OK, I will ask my question tomorrow."* Similarly, when recalling an occasion in the past, P5 said that he would have interacted differently if he knew his colleague was undergoing stress: *"...when I have a disagreement. At that point of time, I see that person she is crazy in that time on her stress levels. I would actually never bother her at that time. Maybe I will approach her later when she is less stressed."* Third, seeing others' stress levels increases users' empathy with their colleagues which is beneficial in preventing conflicts. For example, P9 indicated that *"other people's stress could be as important as mine."* With the empathic concerns, they *"won't fight each other."* And it enabled them to *"first allowing the stress level to be down, and talk in a normal tone."* Fourth, when people notice their colleagues are stressing out, they would be willing to offer help spontaneously. Like P4 reported, she would ask her coworkers if she could do something for them to support their work: *"Probably I will ask my coworkers that 'is there anything I can do for you, and do you need any help?' I have enough space because I'm not stressed, so if I can release stress for someone else by taking something of their work, I will do that."* In sum, insights into others' stress-related status would help people reflect on reasons, be more considerate, do things differently and support each other.

Insights into Collective Stress Status

Collective stress is the stress status shared by the whole group or the workplace. When showing collective stress-related data visualization to users, they claimed they would reflect on the reasons from a collective point of view, offer help to each other, discuss the current situation, and initiate collective coping activities (e.g., take a break together). First, seeing the collective stress status triggers users to look for reasons from a collective point of view. For example, P2 stated that seeing collective stress-related information makes group members reflect on themselves and look for reasons together: *"I probably ask them what's going on, find out what's going on as well."* Second, seeing the collective stress-related information could engage reciprocal help. Like P8 stated that if the group is stressed, her colleagues would complain to her and wait for her to report to the boss, because she had the best relationship with the boss: *"They will wait for me to do something. They will complain to me, and I will complain to my boss."* Third, insights into collective stress status encourage constructive conversations. Office workers would get together to interpret the collective status. For example, P4 described that if she and her colleagues could see the collective stress visualization, it would be easier for them to open up conversations: *"it can be an opening to talk about it."* Similarly, P11 also claimed that knowing collective stress-related information: *"can open up with the communication."* As related to triggering conversation opportunities, knowing collective stress status could also enable self-expressions and reinforce office relationships. P12 addressed that it is challenging in his culture to express oneself to others, and the collective visualization *"can be a tool to express ourselves."* In sum, insights into collective stress status would engage reflection and action from the perspective of a group. It would trigger constructive conversations and facilitate reciprocal help.

Comparison between My Stress Patterns and Others' Stress Patterns

Participants would make comparisons with each other and interpret reasons for similar or different patterns: e.g., why they are more stressed or more relaxed than others. First, interpersonal comparisons engage group members to reflect on and interpret the differences. For example, as P2 envisioned, when her team members were stressed but the other colleagues were not, she would think: *"If our team is stressed and the other team is not, it's not fair, I would wonder why they are relaxed and we are stressing out,"* Second, they would ask for help or offer help based on the comparison. For instance, as P3 stated: *"You feel like some confirmation that you are doing well. Maybe the job is too hard for them. You can help the other stressed ones. Like the other way around, you can ask the relaxed people to help you if they have less work or they know how to relax themselves."* Third, comparisons could engage constructive conversations about the interpersonal differences. For instance, P2 would discuss with her stressed teammate that why the other team showed up less stressed than they are: *"is that we are more hardworking than they are, or is it about they are more efficient and finish their task better?"* In sum, comparing stress-related data visualizations with peers would make people reflect on and interpret the potential different, or similar patterns, ask for help or offer help according to the condition, and it would trigger constructive conversations with peers.

Inferences Made Combining the Visualization and Observations On-the-spot

Users would make inferences by combining their observations of the real-world situations with the visualization. First, when users connect their current status with what has been shown on the visualization, they would infer the connections. For example, when P3 saw her stress level rising on the visualization, she would relate the visualization with her current working status and reason: *"is it related to the job?"* Second, they would infer how their own behaviors would affect others by connecting the visualization to their social interactions with colleagues. For example, P2 stated that if she could see what she is saying or what she is doing is raising the stress level in someone else, *"the right thing to do is to adjust."* Third, connecting the visualization to on-the-spot situations could develop empathic concerns for others. For instance, P5 claimed that he would be aware of the context and put himself in other people's shoes through connecting other's body language with the visualization: *"I would be cautious to other people's body language more often to understand what is that stress coming from."* Fourth, the contextualized insights smooth the process for users to give and receive help reciprocally. P8 referred her relaxed situation to less workload in hand and noted she would use her spare time to help with her stressed colleagues: *"I'll see if I can help them."* Fifth, participants claimed they sometimes share similar stressors with their peers at work, which could reflect an 'all stressed' situation on the visualization. Relating these real-life stressors with the visualized stress would engage constructive communications that helped with stress management. For example, P3 related the all stressed visualization to a deadline and claimed that talk to each other about similar stressors *"often helps."* Sixth, connections between the visualization and the current situations can facilitate collective coping. P7 compared the office atmosphere to *"lava"*. He would suggest his colleagues *"go have a break"* when he observed people are not busy. In sum, contextualizing the visualization by on-the-spot observations triggers the most sophisticated reflection and activities. It would engage people to speculate on the reasons, adjust themselves, develop empathic concerns for others, ask for help or offer help, talk to peers and make changes together.

Interpretations on How We Influence Each Other

Users would interpret how they affect others and how others affect them. First, when users interpret the effects of each others' behavior, they would be curious about the reasons. For example, P2 explained that the visualization could help her in figuring out *“how you affect others, how others affect you...and how it affects everything.”* Second, interpreting on how one might affects others engages the user to think twice about his(her) impending behaviors. P11 mentioned that she would think twice that her colleagues *“are not the cause of my stress”* before pouring out her problem to them. Because she thought she should do that *“in situations where it doesn’t really affect the colleagues.”* Third, noticing how people affecting each other is beneficial for efficient collaborations. Like P2 described, in a project people working together can observe how they affect each other through the visualization: *“You were working together better when you were stressed or do you get more outputs when you were not stressed.”* So people can adjust their collaborative strategies to *perform better on tasks together.”* In sum, interpreting how colleagues influence each other would help them reflect on the reasons, trigger greater empathy for peers, and contribute to collective coping activities.

8.4.2 Motivating Factors for Sharing and Expected Audiences

Motivating Factors for Sharing Stress Information

We classified participants’ attitudes towards applying the shared collective stress visualization in their office. The results indicated seven major factors that would engage participants to share their stress-related information with others: to help others, to ask for help, to cope with stress together, to share back to whom shared with them, to encourage the group to maintain good performance, to share interesting data and to show off. The detailed descriptions of these motivating factors and quote numbers can be found in Table 8.2.

The mostly-mentioned factor is ‘help others’. As P8 experienced, her stress status is mainly related to her work. If she has a lower stress level than others, it probably means she has finished her work. So she would take the initiative to ask if she could do something for the stressed colleagues. P5 also indicated that if he is not the only relaxed one in the team, he will share with someone who is also relaxed to *“draw a plan to help people who are not relaxed.”* The second factor is ‘ask for help’, as P10 claimed, he would share to ask for help from others: *“If I’m not able to solve a problem. Then I will discuss it with them. I would share personal stress, professional stress, something without my control, things you expect it going to work, would trigger me to share. For my career, for my problems, for my KPIs, I would share it.”* The third factor in engaging sharing is ‘cope together’, which often happens when people encounter similar stressful situations. As P4 mentioned, sharing stress with colleagues can have a sense

Motiving factors	Description	Num	Example quotes
Help others	Users would share their stress status and coping experiences with peers to offer help.	27	*"who is the not-relaxed one and who is the relaxed one. And then maybe try to draw a plan to help people who are not relaxed"(P5); "when my workload is low I would share, and I would ask if I can do stuff for you"(P8); "say, look, this helps me, perhaps it could help you too"(P3); " it doesn't work for me but maybe can help others"(P12)*
Ask for help	Users would share their stress and troubles to ask for help.	24	*"I'm gonna ask have you ever been this situation before? What did you do?"(P6)*
Cope together	Users would share their stress to find out solutions together.	19	*"we are all feel the same, we have a kind of common feelings. We are all in there together. But if it's long-term, we have to find out what is the problem and what we have to do about it"(P4)*
Share back	If others share with them, they would like to share back.	11	*"When others do, it's easier for you to talk about it as well"(P1)*
Encourage maintenance	Users would share to keep the good performance.	5	*"for the whole team to celebrate, let's keep it that way"(P7)*
Interesting data	Users would share stress with others if the data is interesting.	1	*"I would share if the data is interesting"(P10)*
Showing off	Users would share to show off.	1	*"I'd like to showing off"(P10)*

Table 8.2: Motivating factors that could engage participants to share their stress.

of feeling that they are facing the challenge together, and that she is not alone. And if the stress status didn't go away, they could find solutions together. When other people start sharing, it would also encourage users to share back. Like P4 said, others' sharing would make sharing easier for her, *"I would straightforward to share if someone asks how are you doing. If someone is saying something like, you were a little bit down for a few days, OK, all open."* Whereas they would also consider if the audience is trustworthy and helpful, like P6 indicated *"if in the office people are friendly, it's nice to share and talk."* If the overall performance is good, sharing could happen to keep the good performance. As P7's claimed, if the whole group is relaxed, he would yell out to engage colleagues to keep it. P3 also suggested the whole group to *"do something fun when we are all relaxed."* Other factors like *"I would share if the data is interesting"* and *"I'd like to show off"* are also mentioned by P10.

Who Is Safe to Share Stress with

As illustrated in Table 8.3, we categorized the workplace roles that office workers feel comfortable sharing their stress-related information with. The most frequently mentioned targets are: their boss, colleagues who have a close relationship with them, and colleagues who have similar age/hierarchy/stress conditions.

Who to share with	Num	Example quotes
Boss	9	*"That's his profession to be a manager. The system can help him arrange things reasonably"(P7); "my boss is also my colleague, we always joke and make fun of my boss...you have to make sure the environment is ok, everyone's happy to go to work, wants to work, and doesn't go stressed"(P8)*
Colleagues who have a close relationship with me	9	*"people who get alone really well, those people I would like to share with them" (P5); "I would try to approach one with good relationship in the office"(P12)*
Colleagues who have similar conditions (age, hierarchy, stress) with me	9	*"someone who has same age as me...she would say because you are young or whatever"(P1); "we all on the same line, on the same level"(P8); "they are doing the exact same work. Maybe they were in the same position before"(P11); "someone with similar condition could be more understanding"(P6); "you can both be angry about the same stuff and complain...you will get the feeling of relieve at the end"(P8); "Someone they don't impact your day to day work, but works in the same company"(P11)*
Colleagues who are not stressed	8	*"if you can't manage, you can't help me neither"(P2); "I prefer not to speak to people who are down, because you would drown into it"(P4); "share to people has more stressed than you is like you are showing off"(P7); "if they are relaxed maybe they have some space...they can provide some tips or provide some help"(P12)*
Colleagues who are professionals	7	*"I would ask for help from some other source in the organization who are formal, and have the non-disclosure agreement"(P6); "talk to a counselor"(P9)*
Colleagues who need help	3	*"I would tell who is experiencing stress, I would say like I think you are a little bit stressed. I had it a long time ago and I was doing this and this, and this that helped very well"(P4); "only somebody who needs help"(P5)*
Colleagues who are not the cause of my stress	3	*"If I am stressed because of them, I think I'm not going to talk about it"(P1); "I really would not want to share with them if they are the cause of my stress"(P11)*
A general colleague	2	*"If you don't know people are stressed, you can't help"(P8)*
Colleagues who sit close to me	1	*"I always talk to the colleague who seats close to my table, I share the most with him because that's the easiest"(P8)*

Table 8.3: To whom office workers would (or would not) like to share their stress with and example quotes.

Office workers would like to share stress status with their boss mainly because people with a higher hierarchy (e.g., managers, boss, leaders) are responsible for employees' mental well-being and capable of removing the stressors from an organizational level. Like P9 addressed: *"My boss should know what kind of stress I'm going through. He may give me a holiday if necessary."* Sharing with colleagues who have a close relationship with them made people feel "comfortable" (P4, P7, P11), and they do not need to worry about the data being misused (P3, P6). Sharing with someone with similar conditions would gain more understanding and support. P1 noted she would share her stress-related information with someone of similar age because otherwise they would tell her *"because you are young or whatever"*. Their understandings always made her feel better. P8 claimed she would complain to other stressed colleagues, and she could always gain some encouragement from them. P11 also mentioned that *"if you know that somebody else has the same stress level as you, you would like to share about it because you are not alone."* Sharing stress-related information with someone who is not stressed, on the one hand, *"it wouldn't make the situation worse"(P4)*. The idea is that, people can learn and get help from them because those not-stressed ones are considered to be able to *"manage their stress very well"(P10)*. Professional positions in an organization (e.g., psychologist, counselor) are also popular audiences for office workers. Like P6 addressed in the interview, *"I would ask for help from some other source in the organization who are formal, and have the non-disclosure agreement."* Office workers showed their willingness to help by sharing their stress-coping experiences with peers. And some mentioned they are hesitant and refused to share stress information directly with someone who is causing their stress. For example, P11 noted she knew sharing could fix problems and make people regulate their own behavior, but she chooses not to share to avoid awkward situations: *"I really would not want to share with them if they are the cause of my stress...I feel that I would not really open to share that with them, but it's probably good to share with them. So they can fix it."* Share stress to a general colleague (P7, P8) and to whom they sit closer (P8) are also mentioned. Quote numbers and other example quotes are listed in Table 8.3.

8.4.3 Remaining Concerns on Collective Stress Related Data Visualization

There remain concerns about the collective use of the collective stress visualization. Five participants were concerned that people might interpret the relaxation on the visualization wrongly (P3, P6, P7, P10, P12). For example, P3 and P7 worried her stress data could get finger-pointing: *"I would be scared because* *maybe you are lazy, that's why you are not stressed. I'm afraid they will perceive like that"(P7)*. And P6 was concerned if people would use her data against her: *"Like, hey, you are stressed, you were stressed at this point, that's why you don't deliver"(P6)*. Four people (P4, P7, P8, P10) worried that the sharing of personal stress might bother others: *"I don't like to burden all the people with my problems"(P8)*. Three participants (P6, P8, P11) mentioned the imbalanced power to use such systems in practice. Like P11 said, people who are in a position of power may not care, but people in a lower position might not want others to see their stress. Moreover, two participants (P6, P8) mentioned that even though the visualization is anonymized, they still have concerns about getting recognized in using it in a real-life context. For instance, *"Even though it's anonymous, It's easy to be recognized based on the human reaction if you are in the same physical space"(P6)*. P6 and P8 claimed that stress is quite intimate information to share with colleagues. P1 and P3 explained that they wouldn't want others to know when they were undergoing stress because that may make them look weak. For instance, P1 stated *"When I stressed I wouldn't tell people 'oh I'm stressed', I would say 'oh I'm fine'"*. Last but not least, P2 and P12 mentioned the visualization could be more aesthetically appealing.

In summary, office workers were motivated to connect their collective stress experiences through this co-constructing stories study. And AffectiveGarden performed as a design probe to provoke authentic synthesized use scenarios of a collective stress visualization. Throughout the reflective storytelling session, we identified six design qualities that users preferred to have in collective stress visualization systems: reflection and reasoning, self regulation, empathic concerns, reciprocal help, constructive conversations, and collective coping measures. We further concluded the top motivating factors for sharing stress data (e.g., for reciprocal help) and summarized the workplace roles that users would like to share their stress information with. Finally, we gathered the participants' remaining concerns to deploy such collective stress visualization in their workplaces.

8.5 Discussion

In this section, we relate our findings and propose several design guidelines in order to guide future stress-coping intervention design from a social perspective.

System Design Should Support Users' Further Interpretations of the Displayed Information

According to our findings, other than the three types of insights provided immediately by the system (insights into my stress status, others' stress status, collective stress status), participants also gained insights from further interpretations. That is, they get insights from comparing their stress visualization patterns to others, from combining the visualization and observations on-the-spot, and from interpreting how their stress-status affects each other. Therefore, designers should support or leave sufficient space for users' interpretations building upon the provided information. Here we give an example to facilitate contextualized insights through making the connections between real-life situations and the visualization.

In our findings, participants would combine the visualization and their real-life observations to understand certain circumstances. It is in line with Li et al.'s statements that users would look for contextual information that could help them explain what was happening to them [Li et al., 2011]. These findings imply that system designers could construct connections between the information visualization and real-life contents to augment users' experiences, contextualize their reflection, and help them explain what was happening. For example, when there is an upcoming deadline, designers could design event-driven connections through the visualization. The characters and background in the visualization can be designed differently from the common days that fit into this specific busy period to reinforce users' connections with the real world. One example is Miro [Boehner et al., 2005], an ambiguous information visualization system installed in an office building to provide the overall emotional climate to office workers. Designers mapped sociability to the clustering of the representative characters, which incited discussions among users and developed a contextualized emotional climate expression [Boehner et al., 2007].

Aiming for Reciprocal Help Instead of Peer Competition to Motivate Stress Information Sharing

Interestingly, we found the top motivating factors of sharing stress-related information with others are 'help others' and 'ask for help'. Unlike other collective PI systems (e.g., sharing steps or other physical activities to create positive peer competition), in stress sharing context, the focusing point to motivate sharing should be to support reciprocal help in a secure and harmonious atmosphere. When users saw their colleagues getting stressed or they have some successful or failed stress-coping experiences to tell, they would like to share in order to help others. And users would ask for help if they need it and feel secure to do so. Collective coping activities and reciprocal help would happen when users noticed the overall performance of the group is below their expectations. Therefore, system designers could use these patterns to design customized cues to engage reciprocal help in different contexts. For example, when the system sensed user A is the most stressed individual in the group for a certain period of time, it could push a private notification to user A to suggest him to approach his colleague user B, who is currently not occupied with his work, to pour out his troubles. Mechanisms to find a stress coping network around an individual and facilitate social coping can be referred to Rabbi et al.'s research [Rabbi and Ahmed, 2014]. The researchers collect user's stress before and after their conversations with peers. According to which they determine who among one's social network are most helpful in coping with their stress.

The presence of the 'helping out' process should be designed aesthetically pleasing. Suggested by two of our participants (P2, P12), the visualization could be designed more aesthetically appealing. P4 compared experiencing stress status to climbing a hill, *"You know going on the hill, the stress helps you, but up on the hill you should be careful don't fall."* It inspires future designers to design metaphors to make the reciprocal help process attractive and engaging. For example, the 'helping out' process can be visualized as user B's character 'give a hand' to user A's while climbing the hill. More positive metaphoric ideas can be inspired by Biophilia design [Largo-Wight et al., 2011, Wilson, 1984]. To further engage reciprocal help, designers could further develop rewarding mechanisms. For example, the helpers can collect rewards from helping others with their stress-related situations, which can be further linked to the bonuses of contributing to a healthy workplace environment. With this kind of pleasing and engaging collective coping mechanism, reciprocal help can be supported, sharing might happen more fluently and naturally, and users might feel more secure and beneficial to share their stress status in the workplace. Future design can test such ideas in situ to evaluate the mechanisms regarding the existing interpersonal dynamics in an office space.

Collective Stress Visualization Should Support Nuanced Configurations for Selective Sharing and Anonymity

According to our results, we noticed that users have different requirements on anonymity. Some participants expect the visualization to be not anonymous so that they know who needs help. On the other hand, some participants preferred high anonymity because they were concerned with misinterpretations from others. System designers should consider how to balance users' diverse requirements on data anonymity, and provide nuanced configurations for different workplaces. For instance, the system could support users to make choices flexibly. For instance, users can choose how they expect their feedback to be. They could choose to visualize their stress-related data as anonymous individuals or to put their names on the visualizations and openly share them with peers. For users who are worried about physically being in the same space would cause disclosure, designers can provide options to suggest them joining as part of a unit. The unit is constructed by a user through inviting trusted colleagues. Then the feedback would show an aggregated outcome of the unit as a group instead of an individual. Users can interpret the results with whom they trust and help each other obtaining information reciprocally. If one does not want to share with anyone, designers can complicate the mechanisms to maintain anonymity, such as involving options of fake roles. One can join in visualizing the stress data combined with the fake roles as a unit. Other audiences would see a unit performance, which is actually the stress status from that anonymous individual who doesn't want to share. In this way, anonymity can be sustained, and the perceived collective stress data remains accurate because no fake data are invited in this process. However, as a trade-off, users might get confused about the total number of participants in the visualization. Future system designers can explore more solutions to support selective or partially anonymous sharing.

System Design Could Combine Collective Stress Mitigation with Collective Stress Prevention

According to our results, many people claimed that their collective stress situation could have been mitigated if they had this system in their workaday context because they would have more understandings of what is going on inside the workplace and be more thoughtful about their interactions with others. Moreover, office workers indicated that the system could help them identify when the opportune time for collaboration is and when to pull back, which inspires us to design for collective stress prevention. Other than only providing the stress information and letting users figure out the current situations, the system can also provide cues to 'suggest collaborations' or 'avoid conflicts'. And it may also suggest collective activities such as 'coffee break' or 'microbreaks' [Ren et al., 2019] as stress prevention approaches. In this way, users are able to 'read' the collective atmosphere more easily and act on it with less time spent in interpretation and make decisions. Noticeably, system designers should be cautious about the presentation form as well as the notification time. The opportune stress intervention delivery time can be predicted by multiple data, such as computer usage, intervention history, and activities [Sano et al., 2017]. Designers can refer to these data [Sano et al., 2017] to facilitate them in determining a good timing of feedback.

Design Actionable Suggestions That Have Flexible Options and Clear Progress Indicators, and Can Fit into the Context

Our results suggest that users would try out the suggested stress-coping actions from the AffectiveGarden system. Meanwhile, they would also do other things they either tried before or believe to be effective from their previous stress-coping experiences. Therefore, intervention design should leave options open [Li et al., 2011], engaging users to try out new things and also allowing them to practice techniques they are already familiar with to cope with stress status.

Many participants implied the need to take stress level trajectories under control. For example, P1 claimed she would not want to finish the whole day's work with a red performance before leaving. Therefore, system designers should provide achievable suggestions that could satisfy users' self-efficacy to act on it and see the progress of their efforts. Such as in the Fish'n'Steps project, users can take steps and observe their achievements right away from a progress bar [Lin et al., 2006]. By hinting to users that they can make a difference toward a healthy goal from doing a specific activity, the system can expect users to practice the target behavior in future applications.

Our findings also indicate that users might refuse to do the suggested stress-coping action because they consider it cannot fit into their context in terms of time and places. For example, P4 claimed she wouldn't take deep breathing suggested by the system because *"It's just not my thing. Of course it helps a bit. I just know it's not the thing for me."* Whereas she would take other coping strategies. *"I would definitely talk with someone about it...Someone who can relate to you in this situation, who can talk along with you, that would be enough."* Therefore, the system design should provide flexible and smart stress-coping suggestions, which are context-fit. For example, the system can be developed to learn each user's preference on stress-coping techniques that they consider helpful, and customize the interventions accordingly for the users.

Take into Account Interpersonal Dynamics and Asymmetrical Nature in Workplaces

Some of our participants mentioned workplace hierarchy may influence people's experiences in using AffectiveGarden, which encouraged us to think about the use of such systems in practice. On a practical level, the introduction of such technology implies constant or regular tracking of office workers' physiological data. If such a stress sensing technology is allowed, its adoption should be voluntary rather than enforced.

Our current system focuses on self regulation and local management of stress. Yet workplace relationships are in practice as asymmetrical (i.e., some people decide and others have to comply). Locating the source of stress in the individual worker puts the spotlight on the workers' responsibility in the stress rather than on larger structures and chains of responsibility. However, self-related data plays an irreplaceable role for reflection in a collective stress coping context [Xue et al., 2019]. Future designers could handle this conflict through changing the permission of accessing stress data for different stakeholders. For instance, workers can access their detailed stress data on their own personal devices, working groups can access an aggregated group performance on a shared display, external actors who have the power to enforce changes in companies can access unidentified stress data from each working unit (e.g., a department).

8.6 Limitations and Future Work

The findings in this chapter are based on user reflections rather than real experiments with using AffectiveGarden system. Therefore, broader negative impacts of tracking and sharing personal data might get underestimated. Our current findings could not suggest introducing such a system in practice would always head in a positive direction; however, we identify ways to inform future system design to avoid possible negative impacts. To understand users' retrospective stories in their specific contexts, we conducted interviews individually. Future research can explore the interpersonal dynamics through group sessions to generate interesting insights and better serve the goal of collective stress coping.

8.7 Conclusion

This chapter explores the office workers' collective stress contexts and their perspectives of applying a visioned collective stress visualization, AffectiveGarden, anonymously in their specific context. We utilize the co-constructing stories approach to understand users' past experiences, collect their expectations on the visualization design, and identify the visioned applications of AffectiveGarden. Based on the results, we identify six desirable design qualities of collective stress visualization: reflection and reasoning, self regulation, empathic concerns, reciprocal help, constructive conversations, and collective coping measures. Moreover, we identify the factors that could engage stress data sharing as well as the workplace roles people would like to share with. We also surface users' concerns and possible negative impacts the system might bring in practical use. With the promising findings of this study, we demonstrate the plausible applications of collective stress visualizations and translate users' needs to design guidelines for future design and research.

Chapter 9

Conclusion, Limitations and Future Work

This thesis explores how to facilitate collective stress coping step by step toward management in the workplaces by visualizing the stress-related physiological data to groups of office workers. Figure 9.1 gives an overview of the thesis and the process towards the key finding. We start with designing workplace collec-

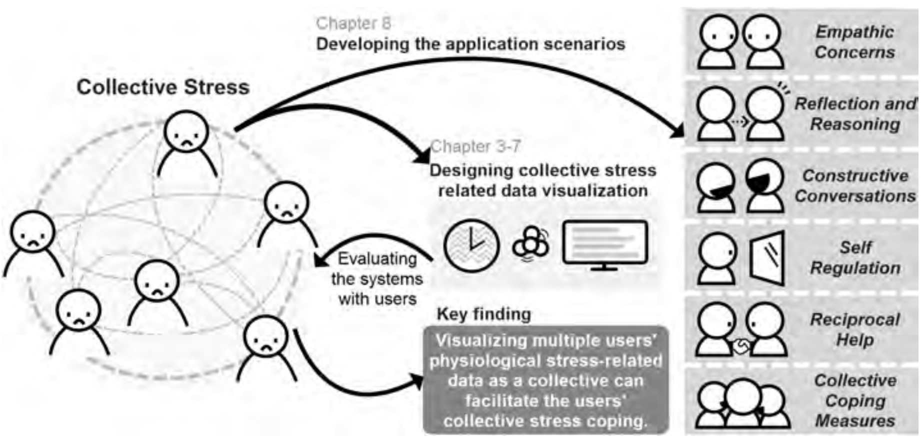


Figure 9.1: A visual overview of the thesis.

tive stress-related visualizations for creating awareness and reflection for office workers. And we find visualizing multiple users' physiological stress-related data as a collective can facilitate users' collective stress coping. We categorize how the visualization would facilitate stress coping into 6 clusters. This Chapter includes answers to our research questions, limitations of this work and directions for future research.

9.1 Answering the Research Questions

RQ1: How could a visualization design raise the awareness of collective stress for office workers?

Short answer: An aggregated visualization of collective stress can make office workers aware of the group's stress status in a shared context. It is valuable for users to see the identifiable individual information in a collective context for raising their awareness. A biofeedback system that visualizes people's physiological stress-related data (e.g., HRV) can increase user's awareness of their inner status and engage their self-regulation.

With the contextualized understandings about collective stress characteristics, in Chapter 4, we proposed a Wizard-of-Oz intervention – ClockViz, an augmented reality installation overlaid with static or dynamic projection to visualize different collective stress statuses on a clock. We integrated and expressed three different statuses of the overall collective stress situation (everyone feels stressed, some members feel stressed, and no one feels stressed) to examine how users experience this integrated visualization. The results from our user study indicated that the integrated visualization could efficiently create awareness of the collective stress status as an ambient information installation. The users' feedback also implied the importance of showing identifiable individual information in a collective context for constructing relatedness and facilitating meaningful reflection.

To further explore how to design interventions to facilitate users' self-awareness and engage self-regulation, we deployed BioFidget that visualizes people's physiological stress-related data through an interactive interface in Chapter 5. Users can see their physiological stress changed with their respiration training over time. The results suggested that visualizing physiological stress-related data increased users' awareness of their inner states and engaged their self-regulation through interaction.

RQ2: How could a visualization design facilitate the reflection on collective stress for office workers?

Short answer: A shared display that anonymously visualizes multiple users' physiological stress-related information can facilitate meaningful reflection on collective stress. It can improve the communication of sharing, and it can evoke individual reflections and social reflections. Anonymity can prevent the visualization from generating additional stress to users.

Based upon previous experiences in designing visualizations for stress awareness, we designed AffectiveWall as a shared display that anonymously visualizes the individual's physiological stress-related information as a collection of the stress status from multiple users. We collected and mapped group members' stress-related data onto a timeline to enable people to make meaningful inter- and intra-personal comparisons without generating additional peer pressure. The results from our user study indicated that AffectiveWall transferred the individual's physiological data into a stress index shown in a shared context, drew awareness of collective stress, and further motivated them to compare their physiological signals and their subjective feelings in both individual and organizational context. It evoked self and social reflection and improved the communication of sharing. However, it is limited as we only explored short-term reflection on the acute stressors applied to the users in an idealistic lab setting.

We, therefore, extended the previous study by deploying a shared physiological data visualization over an extended period in a realistic field setting. Specifically, we deployed the system anonymously on a shared display with small groups of office workers to understand how they use such visualization to reflect their daily stressors with their everyday activity. Although the collected physiological data were noisy due to the practical constraints in the field settings, we found the participants still increasingly agreed with the system and used the visualization as a reference for their subjective stress assessment. They compared their subjective feelings with the visualization over time (individual reflections) and shared their awareness and interventions through comparing with peers (social reflections). Although the data collection was less reliable than our previous system by nature in the field deployment, we still suggest future research to use shared, anonymized heart-rate variability visualization as a tool for facilitating the reflection of collective stress in the field setting. And the system design should encourage users to interpret the differences between physiological data and their subjective feelings.

RQ3: How could designers speculate on the applications of these visualizations for office stress management?

Short answer: Through providing insights about personal stress, peers' stress and the collective stress, users could gain insights from making comparisons with peers, combining with observations on-the-spot, and interpreting the patterns. The collective stress-related visualization could facilitate collective workplace stress coping by increasing users' empathic concerns, encouraging reflection and reasoning, generating constructive conversations, motivating self-regulation, engaging reciprocal help, and inspiring collective coping measures among colleagues.

To gain in-depth understandings of users' needs and envisaged application scenarios toward collective stress management, we constructed use case stories together with a group of office workers based on their lived experiences. We adopted a participatory design approach, co-constructing stories [Buskermolen and Terken, 2012], to elicit in-depth user responses and envisions based on their lived experiences in workday routines. Specifically, we first made narratives for office workers to relate to their past experiences on collective stress and trigger them to articulate their expectations on how collective stress visualization would be implemented in their real life. Then, we introduced a design concept (AffectiveGarden) as an anticipated future to evaluate fictional scenarios based on their own context. The results yielded a rich categorization of insights that users expect to gain from the visualization, and six clusters of envisaged benefits in facilitating collective stress coping were identified: *reflection and reasoning*, *self regulation*, *empathic concerns*, *reciprocal help*, *constructive conversations*, *collective coping measures*. This study revealed the potential opportunities of collective stress visualizations via co-constructed authentic usage scenarios, which translated users' needs and desires into design implications for future research and practice. We would suggest future group informatics system design as follows: (a) system design should support users' further interpretations of the displayed information; (b) aiming for reciprocal help instead of peer competition to motivate stress information sharing; (c) collective stress visualization should support nuanced configurations for selective sharing and anonymity; (d) system design could combine collective stress mitigation with collective stress prevention; (e) designing actionable suggestions that have flexible options and clear progress indicators, and can fit into the context; (f) taking into account interpersonal dynamics and asymmetrical nature in workplaces.

As an overview, Figure 9.2 illustrates the relations between theoretical background, design activities, and main contributions. From top to bottom, we identify design opportunities from the perspectives of stress and collective stress,

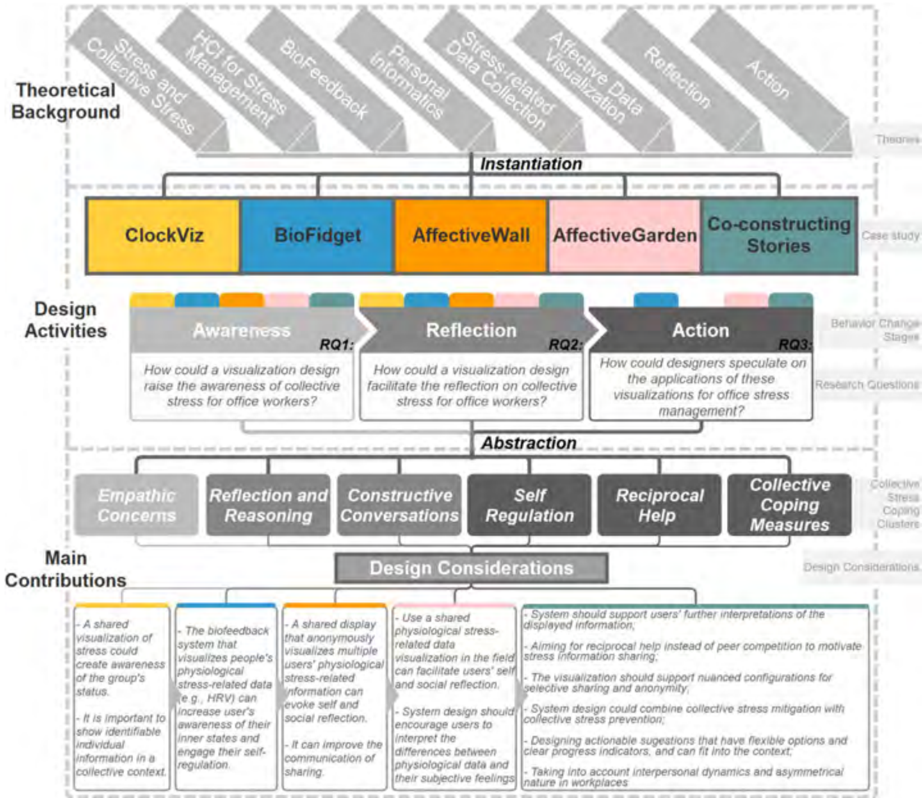


Figure 9.2: A visual summary of how we answered our research questions.

HCI for stress management, biofeedback, personal informatics, stress-related data collection, affective data visualization, reflection, and action. We integrate these theoretical background and instantiate our hypothesis through design activities. Each color represents a case study that matches relative behavior change stages in the next layer. Then we abstract the findings from each study and conclude six clusters of collective stress coping approaches: *empathic concerns*, *reflection and reasoning*, *constructive conversations*, *self regulation*, *reciprocal help*, *collective coping measures*. In the bottom layer, we conclude design considerations that extracted from our practices for future collective stress related intervention system design.

9.2 Limitations

There are a few limitations in this thesis. First, most of the studies in our research were conducted over a short period of time, which may not be adequate to obtain how office workers experience the collective stress visualization design in the long-term. Second, the physiological stress sensing did not work well during the field deployment. Future researchers still need to develop reliable sensing to conquer this barrier to support field use. Third, the participants in our studies might not be representative of a larger population. For example, most of our user studies had Ph.D. researchers as our main participants. The nature of work may differ from employees in industries. How the change of working context affects users' experiences needs to be further explored.

9.3 Options for Future Work

Explore Other Stress Measures Stress can be understood through various proxies. Our research chose one of the common instruments – biosensors (e.g., [Mark et al., 2014]), as our approach to collect a stress index. Proxies like smartphone usage [Wang et al., 2014], sleep patterns [Rodgers et al., 2016], other quantitative assessment approaches [Singh et al., 2015, Lachman and Weaver, 1998, Misra and McKean, 2000], and qualitative approaches [Kelley et al., 2017, Lee and Hong, 2018] can also be stress indicators for future feedback design explorations. The interpersonal stress coping scale can also be applied to assess coping performance in future research [Kato, 2013].

Explore Applications in Other Specific Contexts Throughout our research, we hear participants mentioned a couple of times that they thought this system might be very helpful in a specific context, such as competitive sports [Fletcher et al., 2008]. Future work can further investigate new design opportunities for these specific use contexts.

Explore Collective Stress Coping Across the Hierarchy Our current work focuses on the collective stress within co-located peers working in the same unit or organization. We consider small working units as a starting point and try out peers within similar positions. We did not intend to deploy our interventions across the hierarchy. Future research can further explore how to design interventions for collective stress coping across the organizational hierarchy. When people have different responsibilities, performing different roles in the workplaces, how would users experience the system? How to design systems to address the different requirements among different stakeholders? Will there be ethical concerns? (e.g., will managers misuse the employees' data to illegally monitor or increase the workload deliberately?) Will the benefits counterbalance the potential ethical concerns the system brought? These questions open up interesting topics to discuss in future research. Future designs can start with obtaining the needs from the perspective of managers [Dewe and O'Driscoll, 2002].

Explore Collective Stress Coping Across Cultures Facing collective stress, different cultures may have different attitudes. Some cultures may appreciate stressed ones as "heros", but in other cultures people may consider stressed ones as unhealthy or unqualified. The socially constructed interpretation of stress holds different meanings in different cultures [Lansisalmi et al., 2000a]. Not only people's impression on stress shows differences, the experiences of emotion are also enacted cultural narratives [Boehner et al., 2005,Geertz, 1957]. Future designers can further investigate how to design to address the differences in coping behavior [Yeh et al., 2006] across cultures.

Explore Other Channels for Feedback Design Our current intervention stays in visual feedback for shared use because we consider this to be the most efficient way to deliver information with time for co-located multiple users. We did not explore other formats of feedback channels (hearing [Grimes et al., 2010,Yu et al., 2016b], smelling, tasting [Khot et al., 2015]). Future researchers can explore other channels of collective stress expressions in order to deliver information efficiently and aesthetically pleasing.

Explore the Time for Stress Interventions Our current approach follows the classical PI model, provides stress interventions right after or at the same time the physiological stress occurs. Recent works in personal stress management propose designing just-in-time (JIT) or future-centric PI systems to address mental-health-related problems. For example, researchers develop algorithmic approaches to provide just-in-time support, by adapting to the individual user's internal state and context [Nahum-Shani et al., 2018]. MindFocaster [Lee et al., 2020] is a calendar-mediated stress anticipation application that allows users to expect stressful events in advance and generates plans to mitigate the stress. According to previous explorations on intervention timing, researchers envision incorporating a just-in-time mechanism with anticipation (i.e., coping planning) in future stress intervention design to better motivate users to engage in a healthier behavior [Lee et al., 2020]. Future researchers can develop such PI systems for possible stressful scenarios.

Deploy a Longitudinal Study Our current research questions were answered, and abundant insights were drawn. With a longer-term field study, future designers can gain insights to answer different research questions (e.g., whether the current activities we observed might change over time or whether further patterns will be formed). A more extended study allows for a more comprehensive view of how these behaviors change over time, which can be continued as future work.

9.4 Concluding Remarks

We conclude this research by reflecting upon the stages we highlighted: awareness, reflection, and speculation on actions. Our exploration followed the behavior change model [Prochaska and Velicer, 1997] and elevated it to a group level in the stress management context. We investigated social stressors in the workplace for a better understanding of the design context. We spotted the inevitable subjective bias during office workers' reflection process, which has been discovered in previous psychological studies [Nickerson, 1998]. Our design interventions made invisible stress visible in a shared context. We brought up design principles using collective visualization in a social context to raise awareness; we deployed stress-related physiological data visualizations to facilitate reflection; and we probed the plausible applications for the visualizations in collective stress management. We ended up discussing the remaining barriers when designing shared informatics systems in a social context. Our research sheds light on using group informatics systems in a social context toward coping with collective stress. We contribute to the HCI design research field by providing visualization design insights for group informatics system design to raise awareness and facilitate office workers' reflection to manage their collective stress in a social context.

Appendices

Self-report Stress Scales

Relaxation Rate Scale (RRS)

DIRECTIONS:

Please rate your relaxation state *at this moment*.

Not Relaxed	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Totally Relaxed*

Questions of State Anxiety

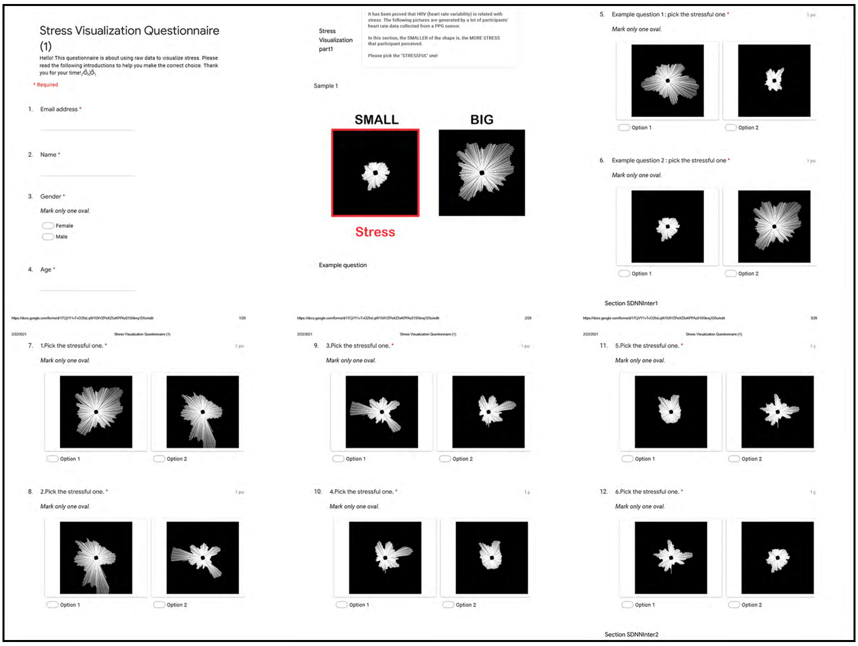
DIRECTIONS:

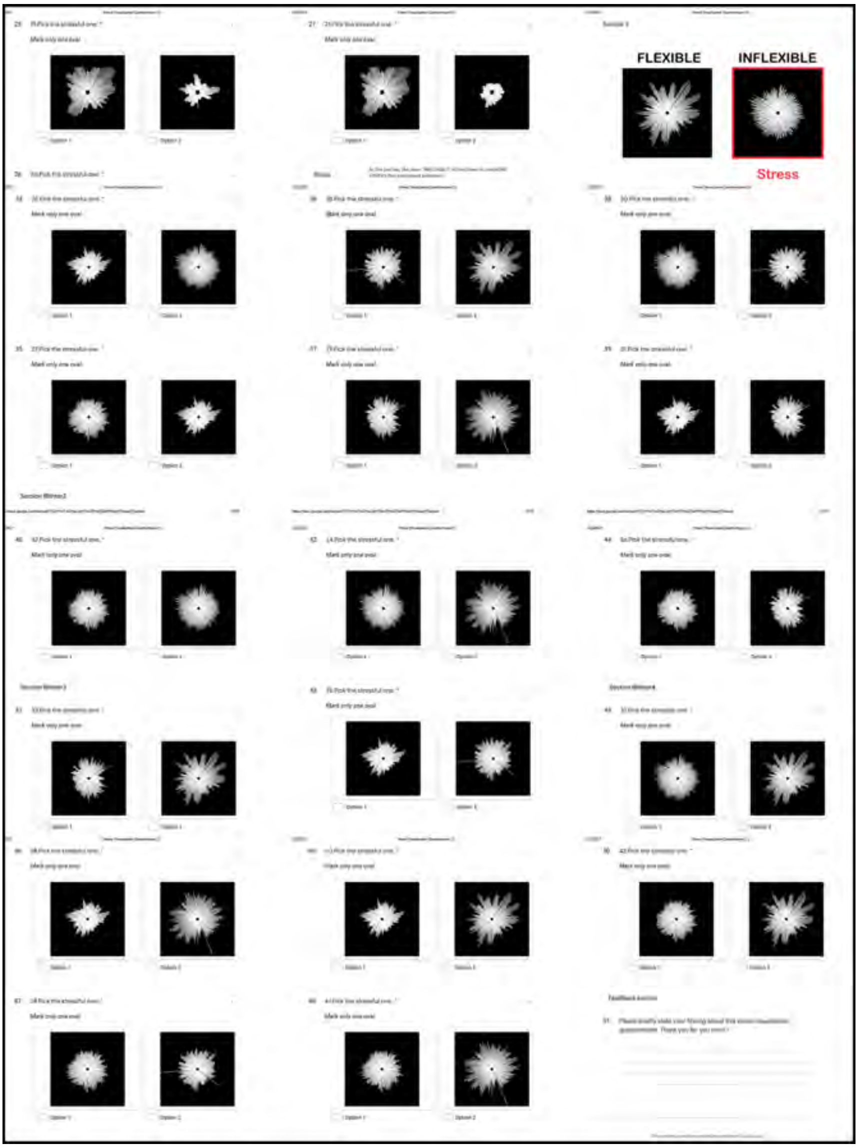
Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	Not at all	Somewhat	Moderately so	Very much so
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery (anxious and nervous)	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

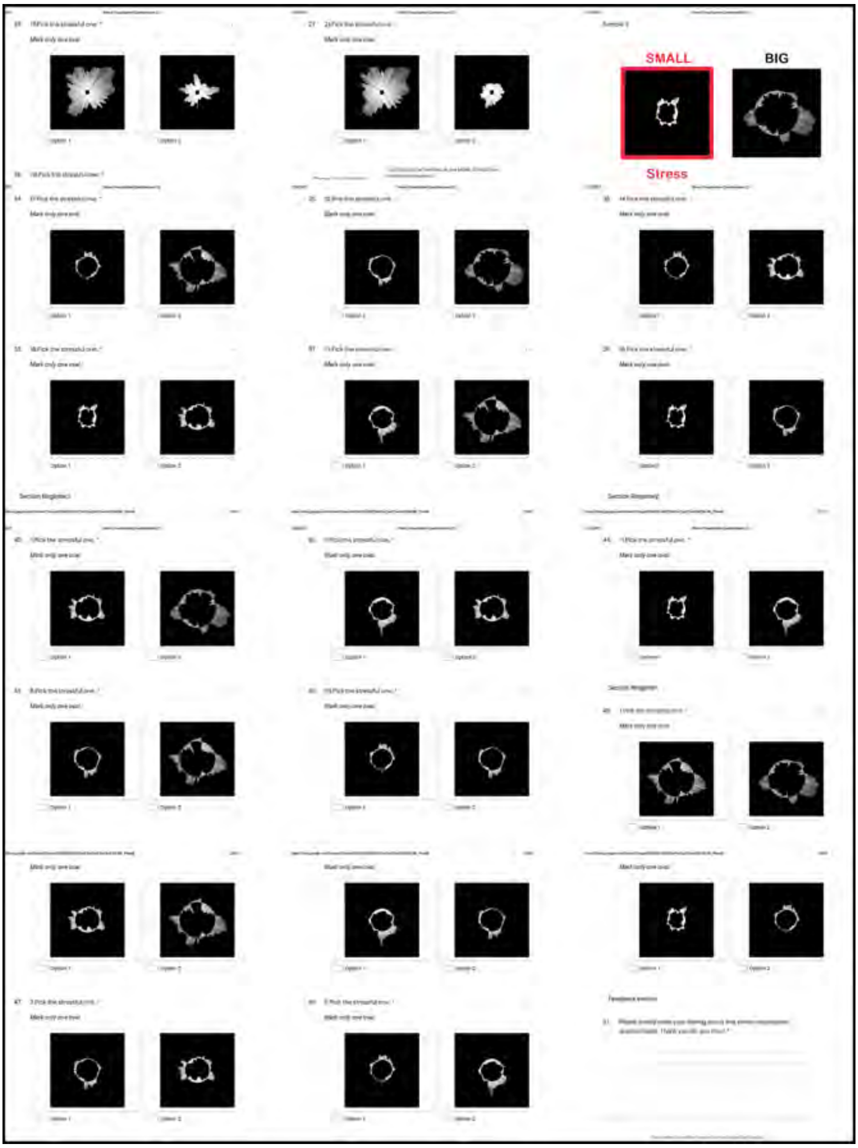
Visualization Questionnaire

Questionnaire (1)




FLEXIBLE
INFLEXIBLE
Stress

Questionnaire (2)


SMALL
BIG
Stress

Questionnaire [1]

Questionnaire [1]

Please answer the following questions based on the 4 TASKS (Video-Math-Video-Math) that you just took.

1. In general, math challenge made you feel more stressful than watch video.

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

2. Please RATE your stress from **1-5** in each task.

(**1:** very relaxed; **2:** relaxed; **3:** neutral; **4:** stressful; **5:** very stressful.)

Task 1 (video watching)	
Task 2 (math challenge)	
Task 3 (video watching)	
Task 4 (math challenge)	

3. What kind of task did you take in TASK 4?

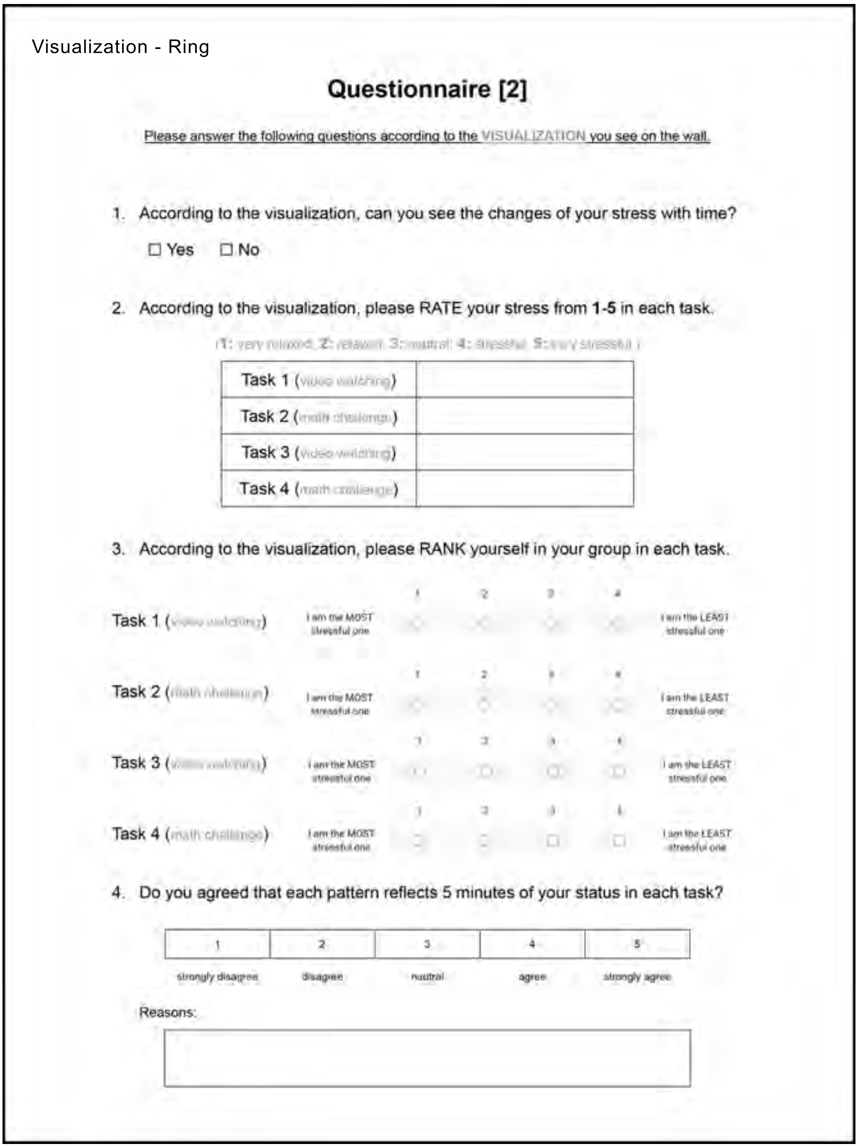
☐ Multiplication (e.g. 34 × 25 =) ☐ Addition (e.g. 49 + 13 =)

4. Which task is more stressful to you? TASK 2 or TASK 4?

Task2 >> Task4	Task2 > Task4	Task2 = Task4	Task2 < Task4	Task2 << Task4

5. Reasons:

Questionnaire [2]



Visualization - Ring

Questionnaire [2]

Please answer the following questions according to the VISUALIZATION you see on the wall.

1. According to the visualization, can you see the changes of your stress with time?

   ☐ Yes ☐ No

2. According to the visualization, please RATE your stress from **1-5** in each task.

   (**1:** very relaxed, **2:** relaxed, **3:** neutral, **4:** stressful, **5:** very stressful)

Task 1 (video watching)	
Task 2 (math challenge)	
Task 3 (video watching)	
Task 4 (math challenge)	

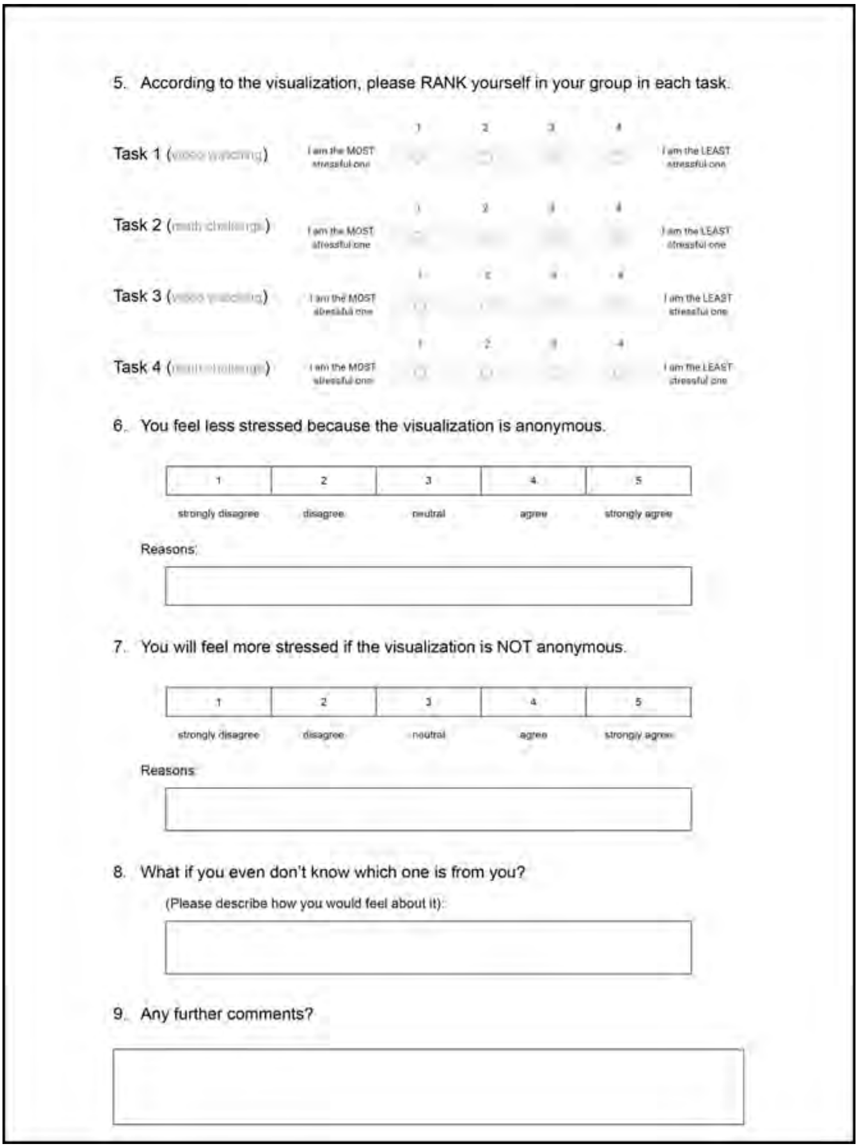
3. According to the visualization, please RANK yourself in your group in each task.

		1	2	3	4	
Task 1 (video watching)	I am the MOST stressful one	☐	☐	☐	☐	I am the LEAST stressful one
Task 2 (math challenge)	I am the MOST stressful one	☐	☐	☐	☐	I am the LEAST stressful one
Task 3 (video watching)	I am the MOST stressful one	☐	☐	☐	☐	I am the LEAST stressful one
Task 4 (math challenge)	I am the MOST stressful one	☐	☐	☐	☐	I am the LEAST stressful one

4. Do you agreed that each pattern reflects 5 minutes of your status in each task?

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Reasons:



5. According to the visualization, please RANK yourself in your group in each task.

		1	2	3	4	
Task 1 ([illegible])	I am the MOST stressful one					I am the LEAST stressful one
Task 2 ([illegible])	I am the MOST stressful one					I am the LEAST stressful one
Task 3 ([illegible])	I am the MOST stressful one					I am the LEAST stressful one
Task 4 ([illegible])	I am the MOST stressful one					I am the LEAST stressful one

6. You feel less stressed because the visualization is anonymous.

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Reasons:

7. You will feel more stressed if the visualization is NOT anonymous.

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Reasons:

8. What if you even don't know which one is from you?

(Please describe how you would feel about it):

9. Any further comments?

Questionnaire [3]

Visualization - NoRing

Questionnaire [3]

Please answer the following questions according to the VISUALIZATION you see on the wall.

1. According to the visualization, can you see the changes of your stress with time?

   ☐ Yes ☐ No

2. According to the visualization, please RATE your stress from **1-5** in each task.

   (1: very relaxed, 2: relaxed, 3: neutral, 4: stressful, 5: very stressful)

Task 1 (video watching)	
Task 2 (math challenge)	
Task 3 (video watching)	
Task 4 (math challenge)	

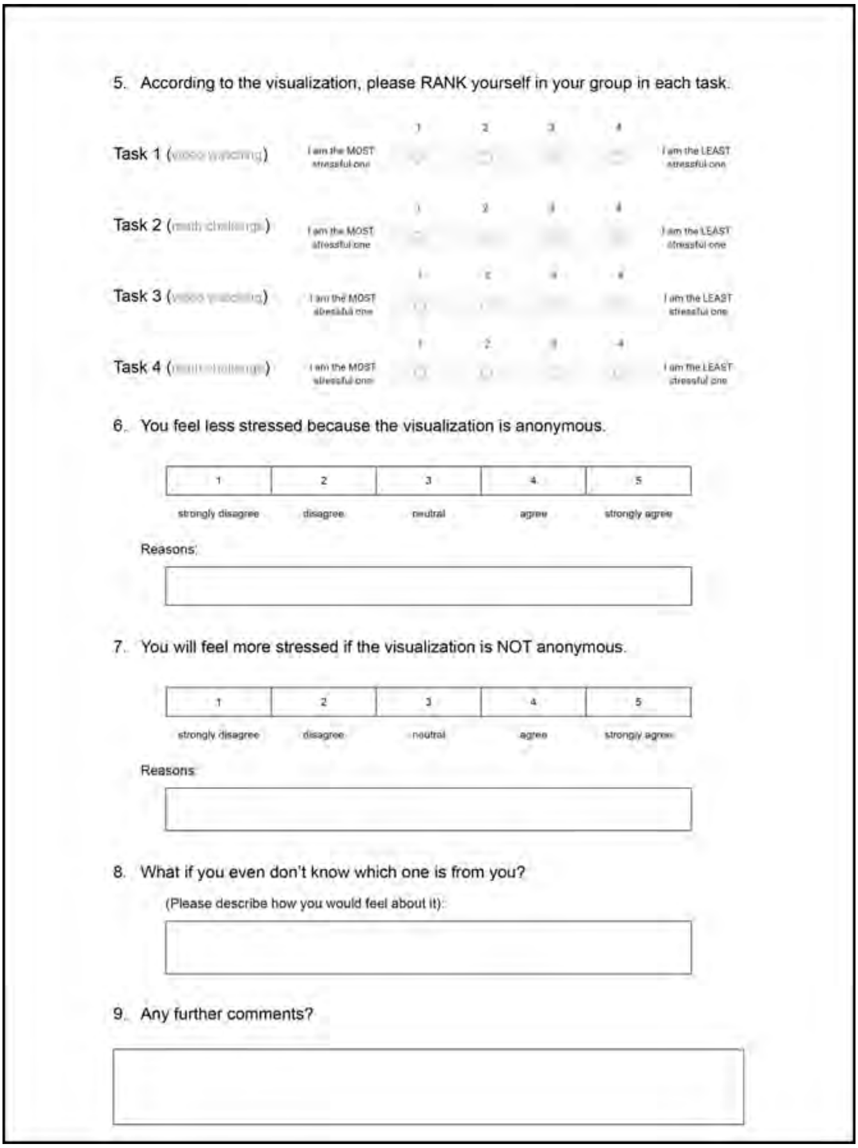
3. According to the visualization, please RANK yourself in your group in each task.

		1	2	3	4	
Task 1 (video watching)	I am the MOST stressful one	○	○	○	○	I am the LEAST stressful one
Task 2 (math challenge)	I am the MOST stressful one	○	○	○	○	I am the LEAST stressful one
Task 3 (video watching)	I am the MOST stressful one	☐	☐	☐	☐	I am the LEAST stressful one
Task 4 (math challenge)	I am the MOST stressful one	☐	☐	☐	☐	I am the LEAST stressful one

4. Do you agreed that each pattern reflects 5 minutes of your status in each task?

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

   Reasons:



5. According to the visualization, please RANK yourself in your group in each task.

		1	2	3	4	
Task 1 (video watching)	I am the MOST stressful one					I am the LEAST stressful one
Task 2 (math challenge)	I am the MOST stressful one					I am the LEAST stressful one
Task 3 (video watching)	I am the MOST stressful one					I am the LEAST stressful one
Task 4 (math challenge)	I am the MOST stressful one					I am the LEAST stressful one

6. You feel less stressed because the visualization is anonymous.

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Reasons:

7. You will feel more stressed if the visualization is NOT anonymous.

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Reasons:

8. What if you even don't know which one is from you?

(Please describe how you would feel about it):

9. Any further comments?

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Summary

Stress is a cultural phenomenon that is socially distributed in organizations. Collective stress, the stress within a group or an organization, describes the stress perceived by the whole group or organization. Similar to individual stress, excessive collective stress may affect individuals' health as well as social collaborations, so the management of these stressors is equally essential. Current solutions for collective stress are mainly distributed in the social psychology field. These approaches contain subjective bias, require specific attention, and can hardly be applied in office workers' busy working routines. With the aid of technologies, Human-Computer Interaction (HCI) researchers provide users with actionable, data-driven self-insight to help them change their behavioral patterns for wellbeing. However, such technological interventions are mainly designed for individual stress management instead of a workgroup. Therefore, we see an opportunity to use technology to facilitate people to catch every nuance of change, to balance the subjective bias, and to improve office workers' understanding of collective stress toward coping with it.

HCI researchers often apply personal informatics (PI) and biofeedback systems for stress management. PI systems offer insights on the parameters that are hardly observable by the users themselves, such as physiological parameters, which can stimulate a user's awareness of their inner state and motivate behavior change. On the other hand, biofeedback systems collect users' biosignals and provide these data back to the users in various formats to bring the unconscious physiological process under conscious control. PI and biofeedback systems both aligned with the transtheoretical model of behavior change, which described the process from raising the awareness, increasing the reflection, taking the action, to sustaining the behaviors. These interventions leveraged visual, auditory, and tactile perceptions of a human being. In this research, we attempted to understand how to facilitate collective stress coping step by step

toward management in workplaces. Since visualizations are expressive and effective in communication, we propose to visualize the stress-related physiological signals to groups of office workers as a means of technological intervention. The main objective of this thesis is to understand how could a visualization design facilitate office workers to cope with collective stress.

The main research question is divided into three subquestions: (1) How could a visualization design raise the awareness of collective stress for office workers? (2) How could a visualization design facilitate the reflection on collective stress for office workers? (3) How could designers speculate on the applications of these visualizations for office stress management? To answer these three questions, we divide the research into three subsequent phases: technology for raising awareness, facilitating the user's reflection, and developing the application scenarios.

Phase 1: Technology for raising awareness: In phase 1 of the study, we designed visualizations as interventions for raising the awareness of collective stress for office workers. First, a Wizard-of-Oz intervention was deployed to understand how a visualization design could raise awareness of collective stress. A design probe that visualizes the organizational stress was applied through a shared display. ClockViz was an augmented reality installation overlaid with static or dynamic projections to visualize organizational stress status on a clock. The installation expressed three different collective stress extensions: everyone feels stressed; some feel stressed while others do not; no one feels stressed. A study was conducted to understand how people experience the two visualizations under different collective stress circumstances. The results indicated that the shared visualization of stress could efficiently create awareness of the group's status; it also highlighted the importance of showing identifiable individual information in a collective context to construct relatedness and facilitate meaningful reflection. Then, to further understand how to design interventions to facilitate users' self-awareness and engage self-regulation, we deployed a biofeedback system (BioFidget) that visualizes people's physiological stress-related data through an interactive interface. Users can see their stress changed with their respiration training over time. In an empirical user study, the visual feedback increased users' awareness of their inner states and engaged their self-regulation through interaction.

Phase 2: Facilitating the user's reflection: In phase 2 of the study, we designed visualizations as interventions for facilitating the user's reflection of collective stress. First, we addressed the insights from previous findings and developed AffectiveWall as a shared display that anonymously visualizes the individual's physiological stress-related information as a collection of the stress status from multiple users. We collected group members' objective physiological stress data and mapped everyone's stress-related data onto a timeline to enable people to make meaningful inter- and intra-personal comparisons without generating additional peer pressure. A user study was deployed with 24 participants from 6 groups in the lab. The results indicated that AffectiveWall transferred the individual's physiological data into a stress index shown in a shared context, drew awareness of collective stress, and further motivated them to compare their physiological signals and their subjective feelings in both individual and organizational contexts. It evoked self and social reflection and improved the communication of sharing. However, it is limited as we only explored short-term reflection on the acute stressors applied to the users in an idealistic lab setting.

We, therefore, extended the previous study by deploying a shared physiological data visualization over an extended period in a realistic field setting. Specifically, we deployed the system anonymously on a shared display with small groups of office workers to understand how they use such visualization to reflect their daily stressors with their everyday activity. We recruited 24 office workers from 6 different workplaces to implement and evaluate the system. Each group was deployed for a week to collect quantitative and qualitative data from the field. Although the collected physiological data were noisy due to the practical constraints in the field settings, we found the participants still increasingly agreed with the system and used the visualization as a reference for their subjective stress assessment. They compared their subjective feelings with the visualization over time (individual reflections) and shared their awareness and interventions through comparing with peers (social reflections). Although the data collection was less reliable than our previous system by nature in the field deployment, we still suggest future research to use shared, anonymized heart-rate variability visualization as a tool for facilitating the reflection of collective stress in the field setting.

Phase 3: Developing the application scenarios: In phase 3 of the study, we constructed use case stories together with a group of office workers based on their lived experiences to gain in-depth understandings of users' needs and envisaged application scenarios toward collective stress management. We adopted a participatory design approach, co-constructing stories, to elicit in-depth user responses and envisions based on their lived experiences in workday routines. Specifically, we first made narratives for office workers to relate to their past experiences on collective stress and trigger them to articulate their expectations on how collective stress visualization would be implemented in their real life. Then, we introduced a design concept (AffectiveGarden) as an anticipated future to evaluate fictional scenarios based on their own context. To adequately sensitize participants about various types of group performances, we showed several narrative storyboards with different group performances. In the end, we conducted in-depth interviews separately with 12 office workers from different professions, and the audio recordings were transcribed and analyzed using deductive thematic analysis. The results yielded a rich categorization of insights that users expect to gain from the visualization, and six clusters of envisaged benefits in facilitating collective stress coping were identified: *reflection and reasoning*, *self regulation*, *empathic concerns*, *reciprocal help*, *constructive conversations*, *collective coping measures*. The results also indicated the factors that may engage office workers to share their stress data as well as the roles in workplaces they would like to share with. As a result, this study reveals the potential opportunities of collective stress visualizations via co-constructed authentic usage scenarios, which translates users' needs and desires into design implications for future research and practice.

We conclude this research by reflecting upon the stages we highlighted: awareness, reflection, and speculation on action. Our exploration followed the behavior change model and elevated it to a group level in the stress management context. We investigated social stressors in the workplace for a better understanding of the design context. We spotted the inevitable subjective bias during office workers' reflection process, which has been discovered in previous psychological studies. Our design interventions made invisible stress visible in a shared context. We brought up design principles using collective visualization in a social context to raise awareness; we deployed stress-related physiological data visualizations to facilitate reflection; and we probed the plausible applications for the visualizations in collective stress management. We end up discussing the remaining barriers when designing shared informatics systems in a social context. Our research sheds light on using group informatics systems in a social context toward coping with collective stress. We contribute to the HCI field by providing visualization design insights for group informatics system design to raise awareness and facilitate office workers' reflection to manage their collective stress in a social context.

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Eindhoven, Feb 2021

Curriculum Vitae

Mengru Xue received her bachelor's degree in Industrial Design from Shandong University in 2013. With her good performance at school (top 5% GPA grade), she was recommended for admission to Zhejiang University as a postgraduate. She received her master's degree in Software Engineering (Information Product Design) from Zhejiang University in 2015. Having received her master diploma, she continued developing her skills in industry and academia. She was an interaction designer at Coohom (Kujiale.com), and then she worked as a research assistant at Fudan University. In September 2016, she started her doctoral research in the Department of Industrial Design at Eindhoven University of Technology, the Netherlands. She was funded by the China Scholarship Council to conduct her doctoral research. The research was focusing on the visualization design for collective stress-related data, of which the results are presented in this dissertation.

List of Publications

Journals

- Xue, M., Liang, R.-H., Yu, B., Funk, M., Hu, J., and Feijs, L. (2019). Affectivewall: Designing collective stress-related physiological data visualization for reflection. *IEEE Access*, 7:131289–131303

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