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PopStress: designing organizational stress intervention for office workers

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Introduction: Excessive work stress on office workers will affect people's health and work efficiency, and organizational stress management is becoming more and more critical. Current studies focus on the management of individual stress. The collective nature of stress and coping needs further exploration.

Methods: This paper proposes the PopStress system, which converts the negative stress of an office group into the energy of a popcorn machine. When the organizational stress accumulates to the threshold, the popcorn machine will start making popcorn and attract office workers to take a break and eat. Through multisensory stimuli such as visual, audio, and olfaction, the system encourages natural and entertaining social stress-relieving behaviors within the office.

Results: Twenty-four office workers were recruited and divided into six groups for the user study. The results showed that PopStress enables users to understand the collective stress status, and successfully relieved the individual's physiological and psychological stress. This work provides insights into organizational stress management, health product design, and social design.

KEYWORDS

organizational stress, biofeedback, stress intervention, multisensory interaction, visual, auditory, olfactory

1 Introduction

Nowadays, office workers are facing an escalating burden of organizational stress. Prolonged exposure to this stress can result in fatigue, depression, irritability, and an increased risk of various illnesses, including cardiovascular diseases (Chrousos, 2009). Apart from individual stress, organizational stress (Lansisalmi et al., 2000) is another type of stress within an organization. Major stressors within organizations are related to interpersonal relationships, including different types of peer pressure and social comparisons (Feslingcr, 1954). Organizational stress could decrease organizational efficiency and job satisfaction (Scott et al., 2006), thereby impacting the individual's health. Therefore, understanding the collective nature of stress and exploring approaches to leverage this situation warrants further research.

Currently, biofeedback technologies have been applied for physiological stress management, but most work emphasizes individuals instead of an organization. Researchers use physiological signals (e.g., EEG, EMG, EDA, HRV) as well as physical features (e.g., facial expressions, vocal tone, and body posture) to collect people's reactions to stress and offer various forms of feedback (Sharma and Gedeon, 2012). Among these, HRV is the most commonly used parameter for biofeedback technology that is considered accurate to reflect physiological stress levels (Yu et al., 2018b). Additionally, research has indicated that taking short breaks in the office setting is helpful in recovering from stress (Burkland, 2013; Kim et al., 2017). Consuming appropriate food and engaging in social interactions can reduce stress (Vink et al., 2007). Fostering social interactions and enhancing interpersonal relationships among colleagues can improve work efficiency (Cameron and Webster, 2005; Hawkey et al., 2005). Most research on stress management is focused on visual and auditory feedback to alleviate individual stress using screen-based or environmental interactions to visualize stress and provide feedback to individuals (Yu et al., 2018b). Some researchers have explored the impact of visualizing organizational stress on office groups (Xue et al., 2019), but there is relatively limited research on using tangible interactions and multisensory approaches to explore organizational stress management. Furthermore, many studies have used relaxation training in specific scenarios (Yu et al., 2018b), such as office yoga. While these approaches can alleviate stress to some extent, it is greatly limited by time, location, and different work contexts.

To further explore organizational stress interventions for office workers in a social context, we present a tangible multisensory interactive system, PopStress. Figure 1 is the design concept of PopStress. This study involved 24 participants who were subsequently divided into four groups for a total of six sessions(4 × 6 = 24). The system converts the group stress as the trigger to activate a popcorn machine placed in the office. When the organizational stress accumulates to the threshold , the popcorn machine will start making popcorn and attract office workers to take a break and eat. It provides office workers with real-time organizational stress feedback and offers an entertaining and natural way to release stress. Through multisensory stimuli (e.g., visual, audio, and olfaction), the system encourages natural and entertaining social stress-relieving behaviors within the office.

We measured the heart rate signals of each member in a workgroup using wearable photoplethysmography (PPG) sensors and transmitted the real-time heart rate data to a computer through Arduino modules. The heart rate variability (HRV) was calculated as the parameter of an individual's physiological stress. An HRV threshold was settled to trigger the popcorn machine to start working. The proportion of stressed individuals in the group was reflected by the duration and volume of the popcorn machine. The group members can easily notice the organizational stress status through the popcorn machine's multiple feedback. The system delivers real-time information on organizational stress, promotes collective awareness, and encourages entertaining social coping activities. Everyone can enjoy the outcomes of their hardworking together, engaging in casual social interactions, and relieving their stress.

From the study, the findings revealed that participants, through their interaction with the popcorn machine, gained a heightened awareness of the organizational stress status. This interaction also fostered a better understanding and increased empathy toward their colleagues. Moreover, participants actively engaged with the popcorn machine, combining interaction with the enjoyment of popcorn consumption. The break and casual chatting time during this process contributed to alleviating individual psychological stress within the group.

PopStress converts negative stress into positive energy to trigger a popcorn machine in a shared office setting. Through

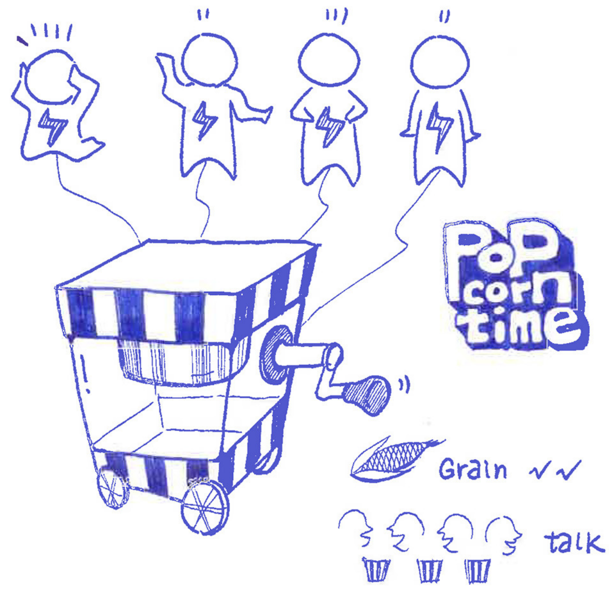

FIGURE 1
The design concept of PopStress. The system collects the organizational stress and converts the stress as fuel to a popcorn machine. People can get aware of group stress through the visual, audio, and olfactory stimuli generated by the popcorn machine. And they can release the stress by taking a break and talking with their coworkers.

interacting with PopStress, office workers are able to be aware of the accumulated stress in their working environment, take a break from work when necessary, and actively change the atmosphere through mutual interactions with colleagues. This work explores multisensory forms of organizational stress feedback. We use PopStress, as a design probe combining multiple sensory stimuli (taste, visual cues, and sound) to encourage entertaining social behaviors toward regulating physiological and psychological stress. We present design principles and discuss future directions and challenges from the perspective of social context in office stress management.

2 Related work

2.1 Work-related organizational stress

Organizational stress is defined as the interaction between individuals and their environment, arising from factors such as high workload, unsuitable working conditions, and lack of interaction among employees. It results in adverse outcomes, including anxiety, reduced work performance, and strained interpersonal relationships (Michie, 2002). Additionally, working with a stressed group, individuals can easily get affected and interfere with each other, leading to the transfer of stress from the collective to individual members (Bakker et al., 2006). Facial expressions and various social activities enable emotional contagion in workplaces (Herrando and Constantinides, 2021). Therefore, noticing organizational stress and alleviating the negative effects is crucial for office workers' health and working efficiency.

2.2 Interactive designs for stress relief

Recently, extensive research has focused on using biofeedback to intervene in workplace sedentary behavior and stress. Among the various approaches, providing visual feedback to users has emerged as the most prevalent method (Yu et al., 2018b). With the help of ambient interaction mode, Hong et al. (2015) used changes in the shape and color of flowers to provide posture feedback to users. The "Breakaway" encouraged office workers to be active by reflecting their body posture through sculptures placed on their desks (Jafarinaimi et al., 2005). MoveLamp increased the number of steps taken by office workers on workdays by reflecting individuals' physical activity through changes in office lighting (Fortmann et al., 2013). Fish'n'Steps promoted physical activity through a social computer game using a display (Lin et al., 2006). Some studies emphasized the importance of being ambient for the intervention designs. Ambient Timer used ambient lighting to remind users of their upcoming tasks without causing distractions while they were working (M'uller et al., 2013). BreathTray integrated continuous monitoring results into the desktop and provided feedback to users to facilitate calmer breathing without distracting their attention (Moraveji et al., 2012).

There are also some examples exploring auditory feedback. Sonic Cradle, which linked breathing with music to enhance meditation experiences (Vidyarthi et al., 2012). Ren et al. (2017) used interactive music to remind sedentary individuals to stand up and move. Additionally, Yu et al. (2015) employed real-time sonification of heart rate variability for biofeedback training. Bhandari et al. (2015) used music biofeedback to regulate users' stress. Gaggioli et al. (2014) found that interactive virtual reality methods were more effective in stress relief than traditional approaches.

Most of the mentioned studies mainly focus on designing interventions for individual stress management, a few studies address organizational stress intervention design. Misinterpreting the stress levels within a group affects work efficiency and employee relationships (Parkes, 1985). Thus, in a group setting, providing feedback to individuals about the overall stress state is crucial for in-time intervention. MoodJam is an application that allows individuals to record and view others' emotional states, and explore feedback mechanisms of group emotions (Li, 2009). MoodLight controls the environment's lighting based on the individual's emotional state, investigating the impact of emotions on oneself and others (Snyder et al., 2015). Wang and Hu (2022) integrate and provide feedback on individuals' information within a work group through digital art, strengthening social connections among individuals. ClockViz projects office organizational stress onto a clock to promote awareness of the organizational stress among the group (Xue et al., 2017). In their further research, they visualized individual physiological stress data and designed AffectiveWall, demonstrating the significance of visualizing organizational stress in increasing awareness, and engaging individual and organizational reflection (Xue et al., 2019). However, current research primarily explores visualization mechanisms for organizational stress awareness and intervention, lacking exploration of more natural ways to offer feedback. Therefore, it is worth exploring multiple organizational stress feedback modalities.

2.3 Data collection related to stress

Stress measurement can be categorized into subjective and objective methods. Subjective methods involve using scales and questionnaires. Well-known stress scales include the Perceived Stress Scale (Cohen et al., 1983), Hassles Scale (Dohrenwend and Shrout, 1985), and PANAS Scale (Watson et al., 1988). Objective methods involve calculating stress based on physiological data. The most commonly used indicator for biofeedback is heart rate variability (HRV) (Whited et al., 2014; Sarabia-Cobo, 2015; Al Osman et al., 2016), with PPG sensors being widely used for heart rate collection (Lemaire et al., 2011; Neiswanger et al., 2015). For instance, Yu et al. (2018a) discovered that combining music with biofeedback significantly improved HRV, reduced stress, and facilitated relaxation. Henriques et al. (2011) found that an HRV-based biofeedback program effectively alleviated stress in college students. Mark et al. measured stress in college students using a combination of subjective methods along with objective methods like heart rate monitors, to help students alleviate stress. The combination of subjective and objective methods resulted in a more accurate stress measurement (Mark et al., 2014).

HRV refers to the variation in time between heartbeats, regulated by the autonomic nervous system (Stauss, 2003). HRV can reflect a person's emotional state and stress levels (Appelhans and Luecken, 2006). Providing users with feedback related to HRV helps them get aware of their stress and regulate it, benefiting their overall well-being (Lehrer, 2007). When individuals experience high levels of stress or emotional fluctuations, HRV tends to decrease (Thayer et al., 2010). HRV is primarily calculated from data collected through electrocardiograms or photoplethysmography, and its computation methods typically involve time-domain analysis (SDNN, RMSSD, PNN50), frequency-domain analysis (LF, HF, LF/HF), and nonlinear analysis (Appelhans and Luecken, 2006). For short-term stress assessment, time-domain methods are more accurate than frequency-domain and nonlinear methods (Pereira et al., 2017). Tharion et al. (2009) measured HRV during student exams and found a significant decrease in SDNN under stress, providing a precise quantification of HRV parameters. Additionally, some research employs respiratory (RESP) biofeedback to alleviate stress (Norris et al., 2008; Bhandari et al., 2015; Wu et al., 2015), while others use galvanic skin response (EDA) biofeedback to detect stress (Feijs et al., 2013; Dillon et al., 2016). Some studies focus on biofeedback and regulation of heart rate to improve stress conditions (Goodie and Larkin, 2006; Peira et al., 2014).

2.4 Summary

In conclusion, researchers and designers have explored interventions for alleviating stress among office workers. Current research focuses on individuals instead of the collective (Xue et al., 2019), and the majority of interventions are based on visual and auditory feedback. Addressing individual stress is crucial, and effectively managing organizational stress is equally important for individuals. However, there is insufficient research on designing interventions that use multisensory interactions to naturally relieve organizational stress in the social context. Therefore, it is essential to build upon the existing visual and auditory organizational stress feedback mechanisms and explore natural and effective multisensory interactions to promote awareness and coping with organizational stress.

3 Design and implementation

The intervention design focuses on creating an interaction between the office workers and a tangible popcorn machine, which provides multisensory feedback on organizational stress status and engages in social activities.

3.1 Design considerations

Through the exploration of related work, four essential design considerations were identified for this design.

3.1.1 The accuracy of data

In the workplace, various personal information can be collected, including physiological data (e.g., heart rate, respiration) and activity data (e.g., posture and water intake). We need to select indicators (HRV) that can accurately reflect an individual's stress status for giving feedback. Moreover, the original data measured by the sensor and the calculation and analysis process of the original data should be accurate enough to prevent the design effect from being affected by too much error.

3.1.2 The rationality of threshold settings

It is essential to design a reasonable organizational stress threshold to accurately assess whether individuals are under significant stress in the group, and the design should align with user intuition. As HRV is influenced by various factors and is highly individualized with significant individual differences, it is inappropriate to adopt a uniform standard for everyone. Instead, individual baselines need to be obtained for self-comparisons. Additionally, it is crucial to set appropriate proportions to reflect the collective stress. The proportion individuals defines a state of organizational stress that needs to be carefully designed.

3.1.3 The intrusiveness of stress reduction measures

In office settings, the primary task of office workers is their job. It is necessary to choose non-intrusive wearable devices for data collection. The feedback should be ambient and not disrupt their main work tasks. Selecting social activities that do not consume too much time as intervention methods is advisable. Furthermore, the design of positive feedback should avoid imposing additional psychological burdens on the users. Therefore, non-intrusive sensing devices and ambient interactive activities can be employed (Morris et al., 2008; Leung et al., 2012).

3.1.4 The authenticity and controllability of stress stimuli

Selecting activities that can progressively simulate work-related stress is crucial. During the experiment, it is essential to precisely control the degree and duration of stress stimuli to elicit high-stress, low-stress, or stress-free states. The challenging game tasks have been proven to be effective in eliciting stress (Haneishi et al., 2007; Bouchard et al., 2012; Quesada et al., 2012). Math problems with different difficulties have also been proved to be effective and commonly used stress induction methods (Xue et al., 2019).

3.2 System design

We chose the combination of group members' HRV as the indicator to reflect organizational stress. PPG is widely used to continuously collect physiological signals in the workplace (Park et al., 2013; Bonomi et al., 2016; Yu et al., 2018c). The collected data is transmitted in real-time to a computer where it undergoes algorithmic processing to measure individual stress levels. Subsequently, it is compared with the stress thresholds to control the popcorn machine, providing multisensory feedback on organizational stress status and enabling timely interventions to encourage social activities and regulate individual stress. Figure 2 shows the design diagram of the PopStress system.

3.2.1 Regarding data accuracy

IBI stands for the time difference between two heartbeats, and SDNN represents the standard deviation of the heartbeat intervals. SDNN has been proven to be the most commonly used and accurate indicator for short-term HRV assessment (Shaffer and Ginsberg, 2017; Clamor et al., 2020). In this design, the collected IBI data is transmitted to a computer, and the corresponding SDNN value is calculated using validated algorithms. A smaller SDNN value indicates higher stress levels for the user. The SDNN is computed with a sliding window of 16 beats (Xue et al., 2019). In this case, it is large enough to include one or more complete respiratory circle, and small enough to be sensitive to changes in breathing patterns (Yu et al., 2018a).

3.2.2 Threshold setting and mapping

To determine individual stress levels, based on existing research (Marina Medina et al., 2012), we set the following criteria. If an

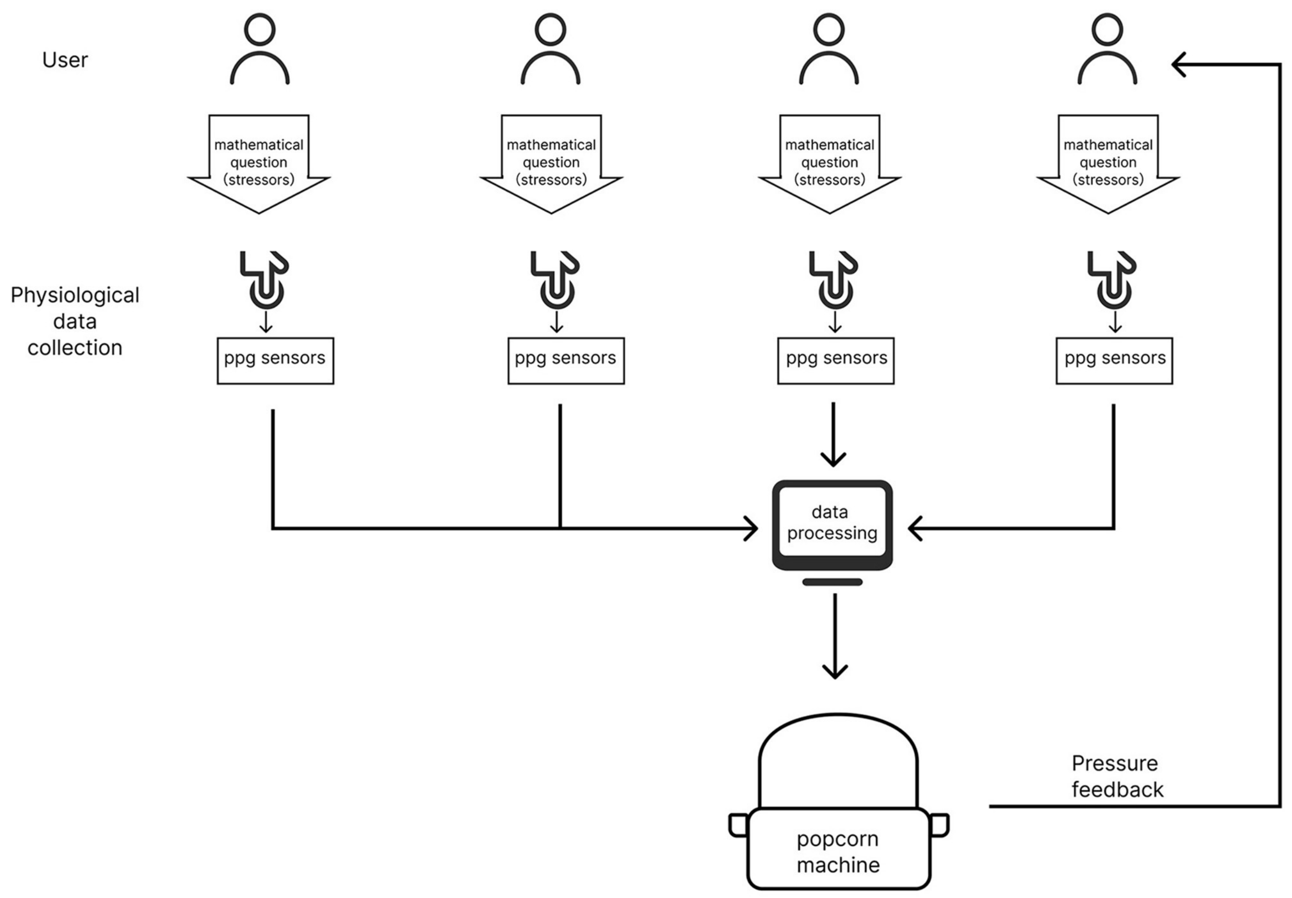

FIGURE 2
The PopStress system design.

individual's SDNN < 50, they are classified as experiencing high stress; if 50 < SDNN < 100, they are classified as experiencing low stress; if SDNN > 100, they are classified as stress-free. In addition, the sdnn value of each user's resting state is measured in advance as the baseline value. Because the baseline value of each user is different, their corresponding pressure threshold should be adjusted appropriately.

Regarding organizational stress feedback, we match the operating duration of the popcorn machine with the number of individuals experiencing stress in the group. The more stressed individuals in the group, the longer the machine works, and the more popcorn will be made. Additionally, we match the volume level of the popcorn machine with the level of organizational stress level. By recording the sound of corn kernels exploding and playing it at different volume levels through a speaker, we assign weighted values (e.g., 10 for high stress, 5 for low stress, 0 for stress-free) to different stress levels. Organizational stress is calculated as the sum of weighted individual stress levels. The higher the obtained value of organizational stress, the higher the stress level at that moment, and consequently, the louder the volume of the exploding audio. This way, users can determine the number of stressed individuals in the working group based on the duration of popcorn kernel explosions and the sweet smell. Additionally, they can gauge the stress levels of their colleagues by the loudness of the sound volume. With visual, auditory, and olfactory stimuli generated by the popcorn machine, office workers are able to notice their organizational stress in time and take a break to release the stress.

3.2.3 Ambient design aligned with the working routine

The wearable form of the PPG sensor allows for stable and comfortable heart rate detection. It neither disrupts the user's daily working routine nor results in significant data loss. When the popcorn machine starts running under organizational stress conditions, users get aware of the group's stress state and participate in small, casual social activities, such as eating popcorn together and talking. These relaxing and small-scale social activities can effectively alleviate stress without wasting too much working time, allowing office workers to schedule collective breaks with colleagues according to the physiological stress status of the group.

3.2.4 Regarding the choice of stress source

To better simulate organizational stress in a work environment, we selected mathematical problems as the stress source. Mathematical problems demand focused mental activity and can be easily adjusted to vary stress levels based on their difficulty. They also facilitate cooperation and competition among individuals of different nationalities and backgrounds, encouraging active participation and mimicking workplace stress. Similar to previous research where varying degrees of math problems were used to create different stress levels (Masanobu et al., 2017), we adjust the difficulty of the math problems to control the level of stress stimuli on users.

4 User study

4.1 Participants

This study recruited 24 participants, including nine females and 15 males, aged between 21 to 36 years (mean = 25, SD = 2.92). The participants were divided into six groups. All participants were graduate students from a university in China, free from any heart-related issues, and provided written informed consent. Within each group, there were four individuals who were familiar with each other to better simulate a real work environment and to avoid adding extra social pressure during the popcorn-eating and conversation process, making the experience more relaxed and natural.

4.2 Apparatus

We prepared a quiet room to simulate an office environment for user testing. Each participant was provided with a computer and a mouse to complete the assigned mathematical tasks. The PPG sensor [1] was securely attached to the participant's left index finger, and the participant's left hand was placed as stable and comfortable as possible on the table. For participants who were left-handed, we placed the sensor on their right hand. Each PPG sensor was connected to an Arduino Uno board, and the sampling rate of the PPG sensor was 500HZ, and the data collected by the four sensors were transmitted in real-time to another PC via USB serial ports. Based on the raw data collected, we calculated the IBI and SDNN values for each participant, reflecting the physiological stress of the group members. Figure 3 shows the participants were busy answering questions to finish the tasks.

The popcorn machine and a speaker were placed beside the workstation to allow continuous data collection from the PPG sensors during the popcorn-eating process. Additionally, to precisely control the heating temperature of the popcorn machine and the timing of the sound, we prepared a speaker and put it near the popcorn machine, and loaded the recorded audio of fried corn kernels in advance. Finally, we connected the popcorn machine and the sound system to the same power strip, and the power strip's switch was placed in a location hidden from the participants' view for easy control. When the SDNN value reached the triggering condition, the experimenter would turn on the power strip switch, and the popcorn machine would start working while the sound system played the recorded audio of popping corn. The volume of the popping sound and the duration of the popcorn machine's operation were adjusted based on the threshold range of SDNN. In Figure 4, the participants eating popcorn and engaging in conversations with their group members.

4.3 Tasks

To better stimulate participants to experience stress in a work-like scenario, we selected mathematical tasks as stressors (Fooken, 2017) to control the stress levels. Before starting the tasks, we instructed them to relax as much as possible, and we measured each participant's baseline stress level. Task 1 involved two-digit addition, designed to elicit low-stress states, while Task 2 involved two-digit multiplication, intended to elicit high-stress states. Participants were provided with a pen and paper for the calculation process.

In each stage, participants were assigned tasks of varying difficulty and were required to complete them within a specified time frame. We used two-digit addition as a low-stress stimulus and two-digit multiplication as a high-stress stimulus (Xue et al., 2019). The experimenters simultaneously monitored, recorded, and marked each participant's answers as correct or incorrect in real-time to ensure that participants took the tasks seriously. During the process, through the collaborative editing of documents by many people, all users can see the progress of other people's tasks in real time, and the countdown clock of tasks is embedded in the documents. The wrong answers marked by the experimenter in real time are helpful to stimulate the stress state of users, so as to simulate the reaction of different people under pressure in office scenes. During the entire task completion process, participants were not allowed to communicate with each other.

4.4 Procedures

As shown in Figure 5, the entire experimental process lasted for ∼40 min. The data collection for physiological responses was divided into the following five stages.

Stage 1: Participants were introduced to the procedure and asked to rest with their eyes closed for 3 min. During this time, the baseline for each participant's physiological stress was measured. They also filled out the Rumination Response Scale (RRS) and State-Trait Anxiety Inventory (STAI) to record their self-reported psychological stress levels before the experiment started.

Stage 2: Two participants were randomly assigned Task 1 (low-stress stimulus), while the other two were assigned Task 2 (high-stress stimulus) to simulate different stress levels in a group, reflecting different situations commonly encountered in office scenarios (e.g., some individuals facing deadlines while others not). Participants had 5 min to complete the tasks, and their physiological stress levels were monitored to check if they reached the predetermined stress threshold. If the threshold was met, the popcorn machine was activated. After completing the tasks, participants filled out the RRS and STAI again.

Stage 3: Participants ate popcorn and engaged in social interactions for 5 min, while their physiological stress levels were

1 https://pulsesensor.com/

FIGURE 3
In the stress phase, participants were asked to finish mathematics tasks within the group.

FIGURE 4
In the relaxed phase, participants were eating popcorn and talking to release stress.

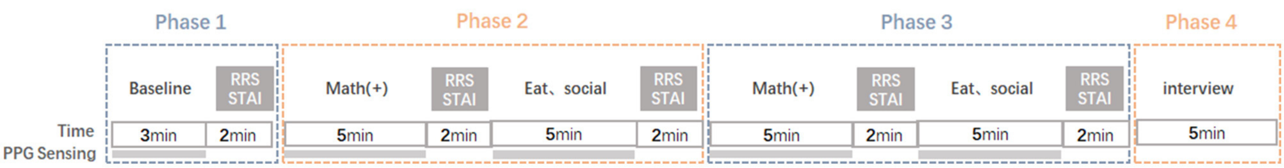

FIGURE 5
The study procedure.

monitored to observe any reduction. Afterward, they filled out the RRS and STAI.

Stage 4: All four participants were assigned Task 2 to simulate a similar stress level scenario, such as everyone facing simultaneous deadlines or departmental quarterly evaluations. They had 5 min to complete the tasks, and their physiological stress levels were monitored to check if they reached the predetermined stress threshold. If the threshold was met, the popcorn machine was activated. After completing the tasks, participants filled out the RRS and STAI.

Stage 5: Participants ate popcorn and engaged in social interactions for 5 min, while their physiological stress levels were monitored to observe any reduction. Afterward, they filled out the RRS and STAI again.

Finally, we collected qualitative data through questionnaires and semi-structured group interviews to analyze the participants' experience and feedback on the whole experimental process. Additionally, the order of Stages 2 and 4 was counterbalanced with each group.

TABLE 1 The individual and group interview questions.

No.	Individual interview questions	Group interview questions
Q1	Do you feel any stress while doing math tasks?	Have you noticed any changes in the volume or working duration of the popcorn machine? How do you think it is related to the group's stress level?
Q2	Can the status of the popcorn machine reflect the organizational stress?	When do you have or don't have stress? Have you noticed that others are stressed? How do you feel about it? Does it make you more relaxed?
Q3	Do you feel more relaxed after eating popcorn and chatting casually?	What was the most relaxing part of the whole process for you? The sound of popcorn popping? The sweet smell when the popcorn machine is working? Or eating popcorn and chatting with others?
Q4	What can be improved in the entire experimental process?	How do you feel about eating and chatting during work to relieve stress? Would you prefer to continue working without being distracted?

4.5 Measurement and data analysis

4.5.1 Physiological data

The physiological signal data measured in this study is HRV data, obtained using a PPG sensor wrapped around the user's index finger to collect heart rate signals. The collected raw data is preprocessed to remove any anomalies. Then, the HRV index, specifically SDNN, is analyzed and derived by Kubios[2] software.

4.5.2 Self-report of anxiety and relaxation

At the end of each stage, we had the participants fill out the RRS and STAI questionnaires to collect their subjective self-reports of relaxation or anxiety levels. The RRS scale asks participants to rate their current level of relaxation on a scale from 1 to 9, where one indicates not relaxed at all, and nine indicates very relaxed (Lesage et al., 2012). The STAI questionnaire consists of 20 items, requiring participants to rate their current feelings, with higher scores indicating higher levels of anxiety and stress (Prinsloo et al., 2013).

4.5.3 Interview

At the end of the experiment, we conducted individual questionnaires and semi-structured group interviews. As shown in Table 1, the questionnaires and interviews focused on the following aspects. First, we want to investigate participants' understanding of the feedback mechanism for organizational stress, and whether the visual and audio feedback could raise their awareness of organizational stress. Second, we want to investigate whether the process of eating popcorn and engaging in casual conversation helped relaxation. Third, we want to investigate whether there are any improvements interacting with the PopStress system and what are their suggestions on our study design.

In the individual questionnaire section, participants had sufficient time and space to express their thoughts, and we then consolidated and analyzed each individual's responses. The interviews were recorded for subsequent analysis. By combining the qualitative data obtained from the questionnaires and interviews with the quantitative data, we aimed to obtain a more comprehensive evaluation result.

2 https://www.kubios.com/

5 Result

5.1 Quantitative results

For the measured physiological data, we first conducted Shapiro–Wilk tests to determine if the data in each stage followed a normal distribution. The results indicated that the data in all stages did not follow a normal distribution. Therefore, we proceeded with non-parametric tests to analyze the differences between the five stages.

Specifically, we conducted the Friedman test to assess the differences among the five stages. Firstly, we compared the two task-related stages to determine if they effectively elicited stress. Next, we compared the two relaxation stages to ascertain if they significantly reduced organizational stress levels.

5.1.1 The process of eating popcorn and engaging in casual conversation enhanced HRV

As shown in Figure 6, the results revealed that compared to the baseline stage (Mdn = 55.65, SD = 25.38), the stress1 stage (Mdn = 43.30, SD = 36.92, p = 0.045) and stress2 stage (Mdn = 51.75, SD = 45.28, p = 0.045) significantly decreased SDNN values, indicating that the stress stimuli effectively elicited physiological stress in users.

Moreover, the Eat-Social 1 stage (Mdn = 58.65, SD = 37.33, p = 0.003) showed a significant increase in HRV compared to the stress 1 stage, and the Eat-Social 2 stage (Mdn = 62.25, SD = 29.55, p = 0.018) exhibited a significant increase in SDNN compared to the stress 2 stage. This suggests that the process of eating popcorn and engaging in casual conversation indeed alleviated users' physiological stress and enhanced heart rate variability.

5.1.2 The process of eating popcorn and engaging in casual conversation reduced subjective stress

As shown in Figure 7, compared to the baseline stage (Mdn = 9.00, SD = 1.10), the stress1 stage (Mdn = 6.00, SD = 2.28, p = 0.000), and stress2 stage (Mdn = 6.50, SD = 2.08, p = 0.001) showed a significant decrease in RRS scores. This indicates that the stress stimuli increased the participants' perception of stress. For the STAI scale, compared to the baseline stage (Mdn = 30.50, SD = 12.12), the stress1 stage (Mdn = 42.00, SD = 11.24, p = 0.005), and stress2 stage

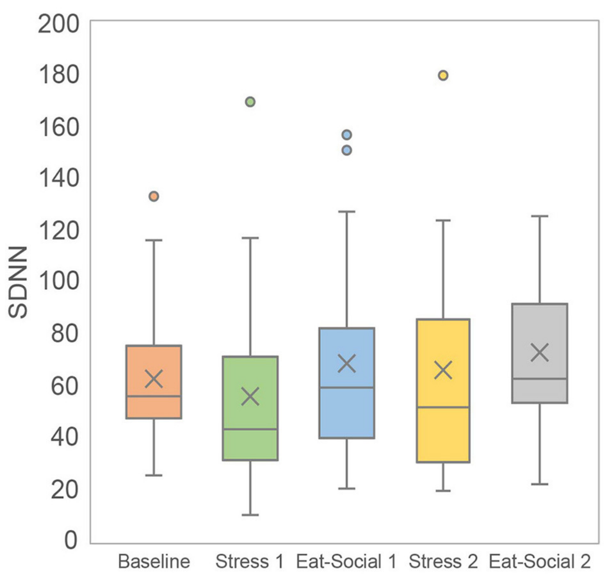

FIGURE 6
SDNN status in five stages.

(Mdn = 39.00, SD = 13.36, p = 0.001) demonstrated a significant increase in scores, showing that the stress stimuli led to a subjective feeling of increased stress.

In contrast, for the RRS scale, the Eat-Social 1 stage (Mdn = 9.00, SD = 1.21, p = 0.000) showed a significant increase in scores compared to the stress 1 stage, and the Eat-Social 2 stage (Mdn = 9.00, SD = 1.47, p = 0.001) exhibited a significant increase in scores compared to the stress 2 stage. Regarding the STAI scale, the Eat-Social 1 stage (Mdn = 31.00, SD = 9.14, p = 0.012) showed a significant increase in scores compared to the stress 1 stage, and the Eat-Social 2 stage (Mdn = 30.50, SD = 10.74, p = 0.000) demonstrated a significant decrease in scores compared to the stress 2 stage. These findings indicate that the process of eating popcorn and engaging in casual conversation subjectively made participants feel relaxed and reduced perceived stress levels.

5.2 Qualitative results

5.2.1 Effect of popcorn machine working duration and sound volume on organizational stress feedback

Most users noticed that the popcorn machine's working duration and sound volume were different and understood their association with the group's stress state. However, the sound of the popcorn machine may have caused negative interference for some users. The results indicated that 22 participants noticed that the popcorn machine started working when there was stress, and 11 of them correctly understood the mapping feedback relationship between stress state and popcorn machine operation. For instance, P11 said, "After the machine started working, I knew that everyone was under stress, and I noticed the increased volume, which made me aware that everyone's stress might have increased." P13 said, "I began to suspect if I was the only one feeling stressed because the machine's popping sound was not as loud." P18 said, "I noticed intermittent noises first, and then the popcorn aroma, and it felt like when there was more stress, the popcorn machine made more frequent popping sounds."

Nine participants reported that the popcorn machine's operation caused negative interference, making it more difficult for them to concentrate. For example, P7 said that the machine's operation intensified the tense atmosphere, and the additional noise increased anxiety levels. P8 mentioned that their attention was disrupted, resulting in decreased answering speed. P12 said that the popcorn machine's sound interrupted their thought process during problem-solving, making it feel like their own stress triggered the popcorn machine, rather than others' stress.

5.2.2 Effect of eating popcorn and casual conversation on stress relief

Most users found that eating popcorn and engaging in casual conversation promptly relieved their stress. The results showed that 22 participants mentioned that the process of eating popcorn and engaging in casual conversation did indeed alleviate their anxiety and stress. Two participants also stated that they did not feel much stress while answering the questions, so there was no significant change during the popcorn-eating and casual conversation process. Among them, P5 said that it eased the intense atmosphere of being highly focused on work, and a relaxed and pleasant environment affected their mood, making them feel more at ease after the conversation. P9 said, "The most certain thing is that eating popcorn helps me regain energy and improve efficiency." P23 said, "I felt much more relaxed, and sweets can make me feel happy."

5.2.3 Other sensory feedback from the popcorn machine

Few users used visual feedback, while many users use olfactory feedback. The results indicated that most users did not mention looking at the popcorn machine working as they needed to concentrate on the math questions. However, a few users mentioned that the visual effect of the popcorn machine popping looked stress-relieving. Besides, the aroma had a significant impact on users, easily capturing their attention. For example, P11 mentioned that they didn't look at the popcorn machine until they smelled the popcorn; then, they looked at it. P3 said that smelling the popcorn made them feel hungry and made it harder for them to concentrate. P10 said that smelling the sweet aroma made them feel more relaxed and aware that the popcorn machine was working due to someone feeling stressed.

5.2.4 Methods and necessity of timely stress intervention

All users believed that engaging in casual conversation indeed helped them relax, and timely stress relief was necessary in the workplace. Eleven participants mentioned discussing the math questions they had just completed. For instance, P11 said, "We discuss the math tasks, and when I find out that others have finished the questions much faster than me, I get a bit anxious." P12 said,

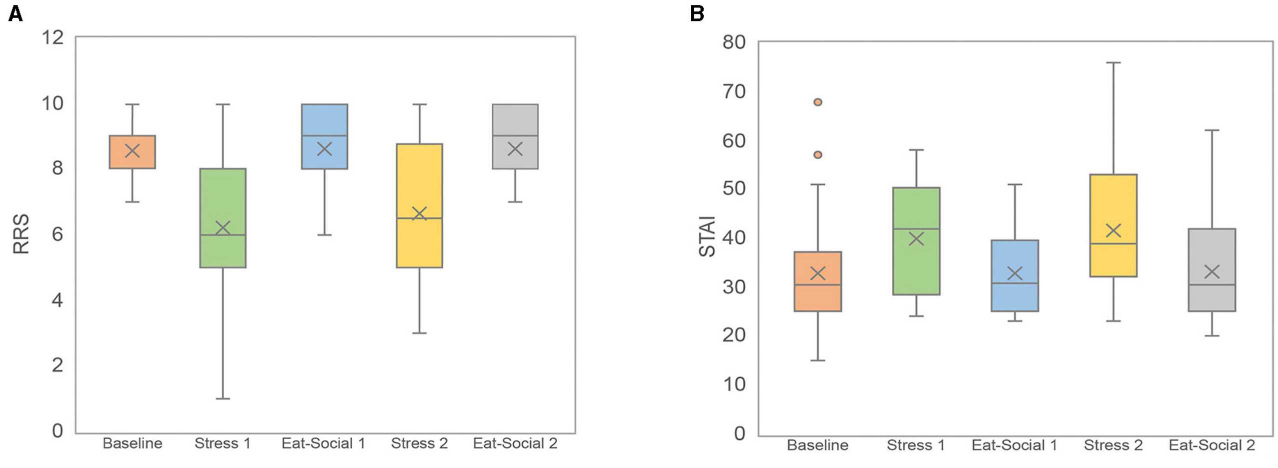

FIGURE 7
(A) The RRS results and **(B)** the STAI results.

"Our chat is about math questions, and I feel more relaxed because I realize that I am not the only one struggling with math problems." P19 said, "We mainly exchange information about our answering speed and approach." Nine participants mentioned engaging in casual discussions about various daily topics. For example, P7 said, "We talk about things around us, like some funny incidents that happened before." Four participants mentioned that they decided whether to participate in the conversation based on their current mood. For example, P10 said, "Sometimes I stay silent, and sometimes I am willing to chat. But when I want to relax quietly, I won't force myself to socialize."

5.2.5 Impact of organizational stress state on individuals

The impact of a group's stress state on each individual varies from person to person. Eleven participants mentioned that knowing that others were also feeling stressed when the popcorn machine popped made them feel more relaxed. Nine participants said that they didn't really pay attention to whether others were stressed, and their primary focus was on answering their math questions. For example, P16 said, "When I heard the popping sound, I felt like everyone was under significant stress, and it also made me relax a bit." P2 said, "Actually, I am highly focused on math, to the extent that I don't pay much attention to whether others are stressed at the moment."

6 Discussion

6.1 Explore multiple physiological signal fusion

In this study, we used only the PPG sensor to measure heart rate and calculate HRV as a stress indicator. In future research, other sensors can be used to measure multiple physiological signals, and then the multimodal data can be fused at the data layer, feature layer, or decision layer to provide more accurate representations of stress levels and make the results more persuasive. This approach is not limited to stress measurement and can be applied to other emotional indicators as well.

One approach is to measure various signals such as skin conductance and respiration (RESP), extracting significant features from different signals, and then fusing them to achieve more accurate emotion classification. For example, Hssayeni and Ghoraani (2021) fused multimodal data from RESP, electrocardiography (ECG), electromyography (EMG), electrodermal activity (EDA), and skin temperature to evaluate and classify entertainment emotions. Another approach is to innovate algorithms and adjust the weights of different algorithms to improve emotion classification accuracy. For instance, Yan et al. (2022) researched adaptive decision fusion methods for more accurate emotion classification.

6.2 Explore low-interference wearable devices or detection methods

To ensure measurement accuracy, in this study, the PPG sensor was wrapped around the user's non-dominant finger, and the arm movement was minimized. However, this may restrict user's freedom of movement and cause interference, affecting stress levels. Some users reported discomfort wearing the sensor device for an extended period, with shoulder discomfort becoming more noticeable over time. Users also felt the sensors on their fingers during the experiment, affecting their attention and making it inconvenient to answer questions at times.

In future research, exploring more comfortable and stable wearable devices for measurement (Feng et al., 2021) or considering other low-interference detection methods can ensure more accurate measurement results, unaffected by other factors. For instance, LightSit embeds sensors into a seat cushion to detect sitting posture and heartbeat during work without distracting the user's attention (Ren et al., 2019). FLOW Pillow detects user data in a low-interference manner through a pillow shape, improving the sitting experience for the elderly (Ren et al., 2019).

6.3 Explore more diverse emotional stimuli to simulate complex stress in different scenarios

In this study, we used two-digit addition as a low-stress stimulus and two-digit multiplication as a high-stress stimulus. The answering process allowed participants to see the progress of their group members and a countdown clock, promoting positive pressure generation. For example, one participant mentioned that seeing other people's progress indeed generated positive competitive pressure.

In future research, more diversified emotional stimuli can be explored, or multiple stimuli can be combined to simulate various complex stress scenarios. For example, Holmgård et al. (2015) used game technology for simulated interaction to explore the potential for emotional response.

6.4 Explore the combination of multiple feedback methods for a better feedback experience

In this study, we mainly focused on visual, auditory, and olfactory feedback generated by the popcorn machine's operation, as well as stress relief through eating and talking. However, the post-experiment interviews revealed that besides auditory feedback, olfactory feedback was also noticed by users. The sweet aroma generated after the popcorn machine's operation had different effects on different users. Some users felt happy when smelling the sweetness, while others didn't like it and felt hungry, increasing stress.

In future research, combining different sensory feedback methods can be explored, creating stronger and more accurate feedback experiences. For example, some studies have combined speech and text as two forms of feedback to provide more accurate feedback on emotions (Ho et al., 2020). Moreover, considering different feedback methods suitable for different situations and even allowing users to personalize and choose the feedback that suits them best can be considered.

6.5 Explore accurate conveyance of individual status information in group studies

During the interviews, some participants expressed uncertainty about whether the popcorn machine's operation was caused by their own stress or others' stress. This indicates that the feedback on organizational stress needs to be further improved to match each individual's stress status in the group. Some studies have visualized each individual's stress on a public display screen for individual feedback (Xue et al., 2019). Although it is anonymous feedback, it still raises concerns about the exposure of personal information. The current study explored new and more pleasant forms of interactive feedback information. Future research can explore more discreet ways to convey individual status data accurately without compromising user privacy.

6.6 Privacy protection in social settings

Regarding personal privacy issues, researchers need to consider users' diverse attitudes toward personal privacy (Xue et al., 2023). For example, some people may agree to share their stress status openly, while others may not want to disclose their status to others, which could make them uncomfortable or feel intruded upon. Therefore, during the design process, a variety of attitudes toward privacy in the public should be fully considered. This way, our designs can be better applied to prevent unnecessary conflicts and ensure a good user experience due to privacy concerns during use.

7 Limitations and conclusion

This work has several limitations. Firstly, we choose SDNN as the index for stress, as many studies do. We will consider combining multiple indexes of HRV (time domain and frequency domain) or multi-model data (e.g., EDA, EEG) in representing stress in our future research. Moreover, in our future work, we will consider adding a golden standard measurement (e.g., E4 wristband) aligned with the PPG sensor during the user test for post-hoc analysis.

In this article, we designed a physical interactive system called the PopStress to provide real-time feedback and intervention for organizational stress. The system transforms negative stress within an office group into energy for a popcorn machine and provides pleasant multisensory feedback, including taste, visual, and auditory cues, to raise awareness of the group's stress state and encourage natural social stress relief behaviors among office workers. Our results indicate that this process can enhance users' physiological and psychological stress. Additionally, the PopStress system guides users to be aware of the group's stress state and subjectively promotes a sense of relaxation. However, this design is still based on the laboratory environment, and it needs to be further improved if it is implemented in the actual office and other scenes. This work explores the application of multimodal interaction in managing organizational stress, offering valuable insights for organizational stress management, and investigates interactive approaches in developing health-related products in a social context.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

YB: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. MX: Conceptualization, Funding acquisition, Investigation, Project administration, Writing – review & editing, Writing – original draft. JG: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. YC: Data curation, Visualization, Writing – review & editing. JH: Methodology, Project administration, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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