The Stress Relief Effects of Foot Warming during Mental Workload

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Abstract: Stress has become a social problem in recent years, and stress control plays a key role in daily life. Researchers have studied methods of stress detection and spontaneous stress relief such as listening to soothing music and walking in a forest. However, some people are unable to take spontaneous breaks; therefore, the development of a means of taking "nonexplicit breaks," to relieve stress unconsciously while working, is required. In this study, we proposed a stress-relief method that did not disturb working. To relieve stress, individuals warm their feet while working, because their hands and feet often become cold when they are under stress. We examined the effect of stress relief via foot warming, and the results revealed that warming the feet caused an increase in RR intervals related to relaxation levels.

1 INTRODUCTION

In recent years, suicide has become a serious problem among workers, particularly in Japan. In total, 28.2% of Japanese people who died by suicide were employees, and 42.1% of the causes of suicide involved mental diseases such as depression (National Police Agency, 2017). Depression has been found to result from chronic stress (Yuanyuan, 2013), and it is necessary to detect and relieve stress in the work environment to prevent this. Studies have examined some methods of stress detection and measurement. These methods include questionnaires, such as the Perceived Stress Scale 14, which uses physiological signals (e.g., electrocardiograms and respiration waveforms), and behavioral reactions involving a keyboard or mouse movement (Alberdi, 2016). Stress can be relieved using luxury goods, such as tobacco and coffee breaks, and activities such as meditation (Alberto, 2009), walking, listening to music (Taelman, 2009), and looking at natural images (Kotake, 2004; Ikei, 2013). The stress-relieving effects of these methods have been demonstrated in both actual experiences and research.

However, only workers who are able to interrupt their work and take breaks voluntarily can use these methods to relieve stress. Workers who accumulate chronic stress tend to be poor at taking voluntary breaks; therefore, spontaneous stress-relief methods could be ineffective for this group. Moreover, because it is common for workers to be unaware of their own stress levels, they often fail to suspend their work spontaneously and take stress-relieving action. Therefore, there is a high demand for methods that relieve stress effectively while allowing individuals to continue working.

We proposed a stress-relief method that did not disturb work. To relieve stress during work, we presented participants with tactile stimuli to their feet, because this conforms to the workplace environment and does not interrupt tasks. Visual and auditory stimuli can interfere with work, and olfactory stimuli are difficult to present selectively because of diffusibility; therefore, these stimuli were unsuitable for our proposed approach. Of the tactile stimuli, we chose to expose participants' feet to heat during work. The reason for this choice was that the skin temperature of the foot decreases with mental stress (Elam, 1987), and we hypothesized that the opposite would be true.

2 RELATED WORK

Research regarding stress is largely divided into that involving stress detection and that examining stress relief.

2.1 Stress Detection

Research examining stress detection is roughly divid-

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ed into research to calculate stress using biological information with electrocardiography and pulse waves as indicators, and that exploring the extraction of feature quantity using behavior such as keyboard typing and mouse and body movement. In addition, some studies have confirmed the usefulness of psychological questionnaires in stress detection (Alberdi, 2016).

With respect to biological information, it is clear that the RR interval (RRI), which is the R wave interval in the electrocardiogram, and its variance value decrease in stress tasks (Taelman, 2009). The Cardiac Sympathetic Index (CSI) and Cardiac Vagal Index (CVI), which are calculated from the RRI Lorentz plot and were developed by Toichi (Toichi, 1997), are stress indices. Moreover, Hayashi confirmed an increase in CSI scores and decline in the CVI following a stress task, while the opposite occurred after a relaxing presentation (Hayashi, 2018). The skin temperature in the body's extremities is also an indicator of stress. Zenju reported that the difference between the skin temperature on the nose and the forehead increased with pleasant stimulation via classical music and decreased with deep stimulation via scratching sounds (Zenju, 2004).

In addition, behavioral reactions involve using input feature quantities of keyboards and mice (Vizer, 2009; Salmeron, 2014), and psychological questionnaires include the Perceived Stress Scale developed by Cohen (Cohen, 1983) and the Stress Response Scale 18 developed by Suzuki (Suzuki, 1997).

In this study, we selected biological information that could be obtained under experimental conditions while participants were in a sitting position, even during cognitive tasks. Because the RRI and CVI scores increased during relaxation following the cognitive task in our preliminary experiments, we selected them as indicators of stress. We paid particular attention to change rates in these indicators before and after stress relief.

2.2 Stress Relief

As this study aimed to reduce stress in the workplace, we examined related research examining stress relief from the perspective of methods that can and cannot be performed in the work environment. Those that cannot be performed in the workplace but exert stress-relieving effects include forest bathing (Hansmann, 2007; Stigsdotter, 2017) and exercise (Guszkowska, 2004).

Stress relief in work environments is based on active behavior or passive presentation. Mindfulness therapy is an example of an actively performed stress-relief method, and numerous studies have demonstrated that this method exerted stress-relieving effects (Grossman, 2004). However, Bohlmeijer et al. showed that mindfulness did not alleviate depression caused by chronic stress (Bohlmeijer, 2010).

Examples of the stress mitigation method involving passive presentation include viewing natural images (Kotake, 2004; Ikei, 2013), listening to classical music (Yuko, 2011), and inducing respiration (Zhu, 2017). However, these methods stimulate visual and auditory senses, which are important in the workplace, and could affect task performance.

Therefore, we selected foot warming as a stress-relief method that did not interrupt tasks and conformed to the work environment. The reason why we chose this approach was that exposing the feet to stimuli should not interrupt desk work. Moreover, because it is clear that foot temperature decreases with stress (Elam, 1987), we hypothesized that the opposite would be true. In fact, some studies have succeeded in making the impression of drink better by warming user's nose, which is based on the opposite fact that a nose temperature decreases in stress condition (Chie Suzuki, 2014).

2.3 Stress Relief via Warming

Previous studies examining thermal and relaxing effects have verified the effect of wrist warming on stress reduction following cognitive tasks (Ayami, 2017). Although a significant difference in psychological questionnaire scores was observed according to exposure to warming, there was no significant difference in biological information. Furthermore, presenting thermal stimuli to the wrist could inhibit task execution in work environments that involve mainly personal computer use. In addition, this previous research did not explain how thermal stimuli affected users' task performance. Therefore, in the current study, we exposed participants' feet to heat to relieve stress, as we aimed to relieve stress in the workplace without hindering task performance. Moreover, we verified that our method was compatible with the work environment by examining the influence of foot warming on task performance.

3 STUDY 1: THE STRESS-RELIEVING EFFECT OF FOOT WARMING

We conducted an experiment to determine the extent of stress reduction resulting from foot warming during a task, using biological information. Nine participants (seven men and two women, aged 22–25 years) were included in the experiment. To examine the stress-reducing effect of warming, we analyzed change rates for the RRI and CVI. In previous studies, RRI compared between breaks and a Mensa test changed by 0.968, from 0.816 ± 0.13 to 0.790 ± 0.13 (Taelman, 2009). In the transition from a stress state to a relaxed state, we expected the RRI to be 1.033 times the reciprocal number. Therefore, we hypothesized that RRI would change by 1.033 following foot warming.

3.1 Foot-Warming Method

Prior to Study 1, we conducted a preliminary experiment to examine the effect of warming. In this experiment, we exposed participants' toes to a 35° C thermal stimulus, using the Peltier element. However, there was no trend in biological information. We concluded that the reason for this result was that the temperature was low, and the size of the stimulated area was narrow. Thus, in Study 1, we used a Hottie (Figure 1) to warm the entire foot at a high temperature. By injecting boiling water into the water injection port, the contact temperature with the foot increased to 50° C at maximum, as shown in Figure 2, and it is possible to provide a high temperature and thermal stimulus to the large area of the foot, which was not possible with the Peltier element in the preliminary experiment. Regarding the distribution of the presentation temperature, the foot temperature was highest, and the heel temperature was lowest.

Figure 1: Experimental environment and Hottie.

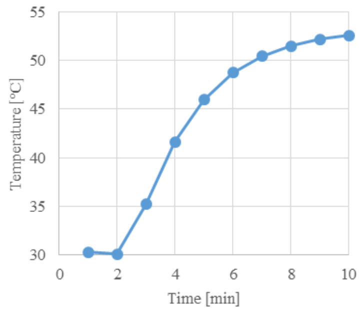

Figure 2: Contact temperature with the foot.

3.2 Procedure

We performed experiments according to the flowchart shown in Figure 3. The experimental environment is shown in Figure 1.

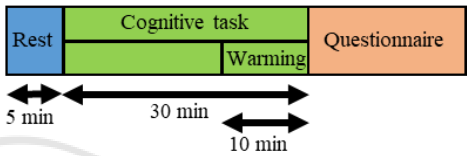

Figure 3: Experimental flow.

3.2.1 5-Min Rest

Participants rested for 5 min before performing a cognitive task. The aim of this stage was to collect biological information while they were a calm state.

3.2.2 30-Min Cognitive Task

Participants performed an n-back cognitive task for 30 min (Kirchner, 1958). Continuous numerical values were displayed on the computer, and participants provided n numbers before the displayed numerical values (Figure 4). In this study, n = 2, and a number between 1 and 9 was presented every second.

There were two reasons for choosing the n-back task. The first was that it was necessary to set a problem with a high degree of difficulty. We had conducted experiments using another task, but it was too easy for participants, and task performance did not change; therefore, we could not verify the effect of foot warming on task performance. The second reason was that it was necessary to impose fatigue on participants, given the work environment. In the n-back task, participants use working memory, which is needed for desk work. Participants provide numbers in the task, using the keyboard, and have not been informed about the task duration.

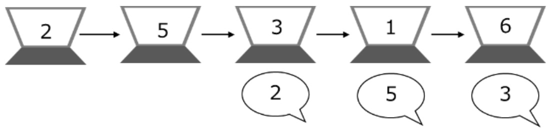

Figure 4: The n-back task. The upper image shows the numbers displayed, and the lower image shows the numbers provided by participants.

3.2.3 10-Min Foot Warming (Temperature Presentation Time)

Warming was performed 20 min after the cognitive task, using a device that connected a silicone tube to a Hottie via a funnel (Figure 1). During the presentation of the temperature stimulus, 1 liter of water was poured manually into the funnel. The temperature of the water differed between the experimental conditions described in Section 3.3. Participants were not informed as to when the temperature presentation would begin.

3.2.4 Questionnaire

After completing the cognitive task, the participants completed a questionnaire concerning the temperature stimulus. The questionnaire items pertained to temperature sensation, pleasure/discomfort, and a free response. Temperature sensation was measured in seven grades ranging from cold to hot, and comfort was measured in seven grades ranging from discomfort to pleasure.

3.3 Experimental Condition Design

To compare the effects of the thermal stimulus, each participant completed two types of task. One task involved a treatment condition in which boiled water was poured at “temperature presentation time,” at a maximum of 50° C. The other task involved a control condition in which water was poured at room temperature (approximately 30° C) at “temperature presentation time.”

Each participant completed the two tasks in 1 day. Participants took a break of at least an hour between tasks. The order of the tasks was counterbalanced across participants. The participants received no information about the experimental conditions.

3.4 Biological Information

It is necessary to measure increases and decreases in stress to verify the effect of stress relief resulting from foot warming. We referred to previous studies and preliminary experiments and used the RRI and CVI scores as indicators of stress.

3.4.1 Electrocardiogram

Electrocardiogram waveforms were acquired using an electrocardiogram sensor. The RRI is an indicator of stress. If the variance value of RRI is large, the individual is in a relaxed state, and when it is small, the individual is in a state of concentration or stress (Taelman, 2009). SCI and CVI scores, which are calculated via Lorentz plot, are also stress indices (Toichi, 1997; Hayashi, 2018). Of the information obtained from these indices, RRI and CVI were used to indicate stress in this experiment.

3.5 Results

RRI is the average value for 1 min, and CVI is calculated using the Lorentz plot of the RRI for 1 min. In addition, the number of correct answers per minute of the n-back task was defined and calculated as task performance. Consequently, the RRI increased after foot warming (Figure 5). We calculated the number of times each index increased 5 min before (approximately 20 min from the start of the cognitive task) and after temperature presentation. The average change rates for the RRI, CVI, task performance, and standard errors under in the warming condition were as follows: RRI: 1.045 ± 0.0106, CVI: 0.966 ± 0.0141, and task performance: 0.912 ± 0.0291. The results observed for the control condition were as follows: RRI: 1.019 ± 0.00679, CVI: 0.976 ± 0.0111, and task performance: 0.980 ± 0.0368 (Table 1, Figure 6). In addition, the rates of change in the warming and control conditions for each indicator were subjected to a two-tailed t test with correspondence (assuming that the population variance was equal). The p values were as follows: RRI: .07, CVI: .60, task performance: .19. The questionnaire results showed that the score for discomfort/pleasure resulting from warming was 3.8 ± 0.8 out of 7,0, and that for the control condition was 3.4 ± 0.4 out of 7.0. Further, the temperature sensation scores were 6.8 ± 0.2 for warming and 3.8 ± 0.37 in the control condition.

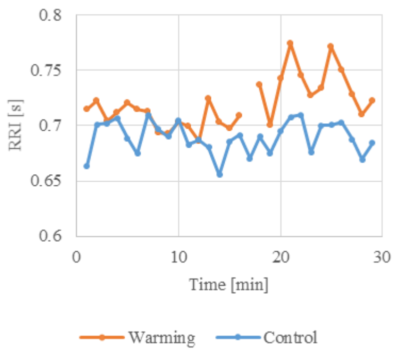

Figure 5: One participant's result for the RR interval.

Table 1: Change rates observed after stimulus presentation.

	RRI	CVI	Task Performance
Warming	1.045±0.0106	0.966±0.0141	0.912±0.0291
Control	1.019±0.00679	0.976±0.0111	0.980±0.0368

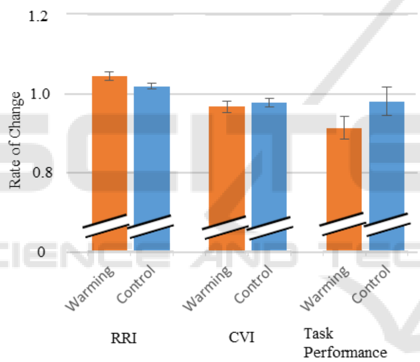

Figure 6: Change rate after stimulus presentation.

3.6 Discussion

We sought to determine whether the two-back task induced stress, by examining task performance reduction. Previous studies showed that stress induced working memory loss (schoofs, 2008). Therefore, two-back task performance reduction could be considered to reflect stress. In the current study, means and standard errors for the first and last 5 min of performance were 52.322 ± 0.853 and 41.753 ± 1.112, respectively. The t-test (one sided, no correspondence, with equal dispersion) p value was <.01, suggesting that the two-back task induced stress.

Comparison of the warming and control conditions showed that the increase in the RRI was greater in the warming condition, relative to that observed in the control condition (p = .074). As the RRI increased by 1.045 ± 0.0106 following foot warming, the change in the RRI resulting from warming was similar to that resulting from rest.

Regarding CVI, although the p value was nonsignificant (p = .52), CVI scores in the warming condition decreased to a level lower than those observed in the control condition. Because CVI scores represent the function of the parasympathetic nerve, they indicated that hyperthermia weakened the action of this nerve. The reason for this finding could have been that the participants were awakened by foot warming.

Regarding performance, although it declined in both conditions, the reduction in performance was greater in the warming condition, relative to that observed in the control condition (p = .19). This decline could have occurred because working memory decreased in the two-back task. In addition, the reason for the greater decline in performance in the warming condition, relative to that in the control condition, could have been that participants in the experimental group became distracted. In the warming condition, the temperature of the foot contact position reached a maximum of 50° C, and many participants reported that the stimulus temperature was high.

Participants' questionnaire responses regarding temperature sensation were as expected, in that they felt warmth upon exposure to heat and did not feel warmth or coldness in the control condition. In the responses regarding pleasure/discomfort, there was little difference between conditions. Notably, one participant answers two out of seven grades (discomfort) in the questionnaire of pleasant/discomfort after warming condition, although his or her RRI changed higher than control condition. That is, the RRI showed a greater increase in the warming condition, relative to that observed in the control condition. Therefore, although the RRI reaction usually occurs in a relaxed state, this subjective evaluation was contradictory.

Based on the above results, the p value for the increase in the RRI was relatively low with foot warming, and task performance declined. In addition, the results showed possible conflict between the RRI result and subjective evaluation. However, there was some doubt as to whether the RRI increase occurred as an effect of foot warming. There are three reasons for this doubt. The first was that, after the experiment, some participants reported that the feeling of water-induced pressure on the foot was pleasant. The second reason was that some participants' RRIs increased in both the warming and control conditions (Figure 7). The third reason was that the RRI increased before the temperature increase in one instance (Figure 8).

Therefore, it is possible that the RRI increased because of the pressure resulting from the water, rather than foot warming. To clarify this issue, the factors underlying the RRI increase were clarified in Study 2.

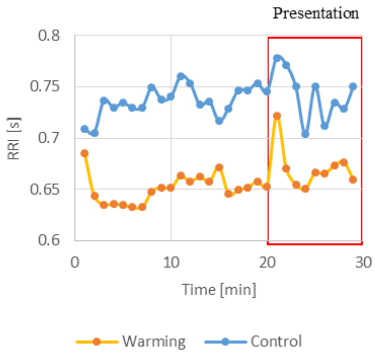

Figure 7: One participant's RR interval.

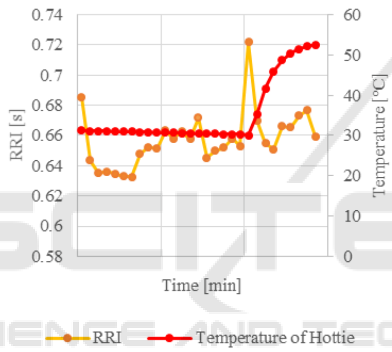

Figure 8: The RR interval and Hottie temperature.

4 STUDY 2: CLARIFICATION OF THE STRESS-RELIEF FACTOR

To determine whether the increase in the RRI in Study 1 occurred because of foot warming or the pressure of the water, Study 2 included the following two conditions. The experimental procedure and environment were similar to those of Study 1. Nine participants (six men and three women aged 22–25 years) were included in Study 2A, and 10 participants (eight men and two women aged 22–25 years) were included in Study 2B.

4.1 Foot Warming Method 2a

We used a cardboard form, as shown in Figure 9, to avoid exposing participants' feet to the pressure of the water. The contact temperature with the foot in this condition is shown in Figure 10. In Study 1, it reached 50° C, and we could not compare the temperature with only that in the condition in Study 1. Therefore, we established the condition in Study 2B.

Figure 9: Cardboard mould in the Hottie.

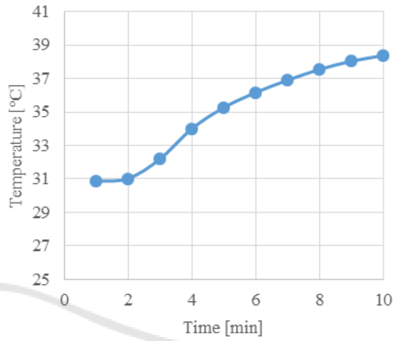

Figure 10: Contact temperature with the foot.

4.2 Foot-Warming Method 2b

To verify that there was an increase in the RRI in the warming condition with the pressure experienced in Study 2A, the temperature of the water was adjusted to that presented in Figure 10. The equipment and procedures used in Study 2 were the same as those used in Study 1.

4.3 Results

Each indicator was calculated using the method used in Study 1. Table 2 shows the increase in the RRI, the CVI, and task performance in the warming and control conditions in Studies 2A and 2B; the results of Study 1 are included for comparison. Figures 11 and 12 show the results of the increase values for the indices used in the warming and control conditions in Studies 2A and B. The results obtained via questionnaire are shown in Figure 14.

Table 2: Change rates after stimulus presentation.

		RRI	CVI	Task Performance
STUDY 1	Treatment	1.045±0.0106	0.966±0.0141	0.912±0.0291
	Control	1.019±0.00679	0.976±0.0111	0.980±0.0368
STUDY 2A	Treatment	1.033±0.0180	0.983±0.0282	0.972±0.0255
	Control	1.014±0.00577	1.040±0.0193	1.003±0.0114
STUDY 2B	Treatment	1.019±0.00742	1.026±0.0224	1.005±0.0217
	Control	1.021±0.00628	0.997±0.0108	1.005±0.0162

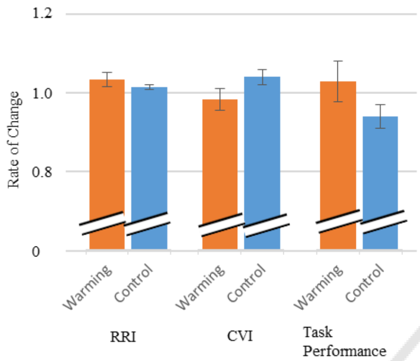

Figure 11: Change rates after stimulus presentation in Study 2A.

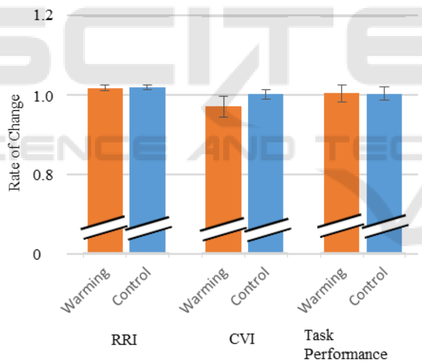

Figure 12: Change rates after stimulus presentation in Study 2B.

Table 3: Questionnaire results.

		Comfort	Temperature Sensation
STUDY 2A	Warming	4.50±0.63	6.00±0.33
	Control	4.22±0.36	3.83±0.29
STUDY 2B	Warming	3.88±0.55	5.44±0.18
	Control	3.89±0.42	3.40±0.22

4.4 Discussion

RRI in the warming condition showed a greater increase relative to that observed in the control condition in Study 2A, but there was almost no difference between conditions in Study 2B ($p = .85$).

In a previous study (Taelman, 2009), weak warming and a break in stimulus presentation increased the RRI to the same extent; therefore, weak warming and pressure impression presentation did not affect the RRI. Looking at the questionnaire of the temperature sense, the warmth is stronger in the order of STUDY 1, 2 - a, 2 - b, and the rate of increase of RRI also follows this order. So it is suggested that RRI increases due to feet warming, and the stronger the temperature sense, the more RRI rise.

CVI scores showed similar trends in Studies 1 and 2. Therefore, regardless of the presentation of pressure, CVI scores decreased following warming, suggesting that warming reduced CVI scores regardless of the extent of the temperature or pressure.

The findings suggested that the RRI increased and CVI decreased with warming. Further, as CVI scores decreased, parasympathetic nervous activity decreased, and sympathetic nervous activity was considered dominant (Toichi, 1997). Moreover, because the RRI increased, participants were at rest, even though they were in a state of stress/concentration.

The results of the questionnaire and temperature sensation was the same way as in STUDY 1. With respect to pleasantness, two participants in Study 2A and three people in Study 2B showed subjective evaluation in conflict with the RRI during warming.

Moreover, task performance showed a greater increase with warming, relative to that observed in the control condition, in Study 2A ($p = .17$). However, there was little difference between conditions in Study 2B ($p = 1.00$). Through STUDY 1 - 2, the task performance was lower only with strong warming conditions (STUDY 1). Therefore, foot warming affected task performance only when the warming temperature was high.

5 CONCLUSIONS

In this study, we examined foot warming as a stress-relief method that did not disturb task performance. In Study 1, we warmed participants' feet during a two-back task. The results showed that the RRI increased and CVI scores decreased with foot warming, regardless of pressure. In addition, sympathetic nervous activity resulting from foot warming was similar to that observed with a break from stimulus presentation. Moreover, the RRI and subjective evaluation were in conflict. Future research is required to clarify the causes of sympathetic dominance and verify reactions with cold stimulus presentation.

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