Empirical Study of Physiological Characteristics Accompanied by Tactile Thermal Perception

Relationship Between Changes in Thermal Gradients and Skin Conductance Responses

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Abstract. This paper presents empirical results regarding emotional changes represented using different thermal gradients by measuring skin conductance responses (SCRs), when providing thermal information with various gradients. Participants attached a probe in their right forearm for thermal stimuli, and SCR measurements were conducted when participants perceived the time to detect a temperature change. The SCR amplitude showed a significant tendency to vary between +0.5 and −0.5 [°C/s] and between +0.5 and −0.3 [°C/s] of thermal gradients. The results of this study showed that differences in clear thermal gradients, such as the comparison between warm and cold stimuli, affected emotion, and differences in detailed thermal gradients, such as the comparison between 0.3 and 0.5 [°C/s] of thermal gradients, did not affect the changes in emotion.

Keywords: Emotion · Skin conductance responses · Thermal gradients · Tactile sensation

1 Introduction

Information presentation technology with tactile stimuli is being widely used for the development of emotion interfaces [1, 2]. A majority of such techniques apply vibratory stimulation [3]. However, the presentation medium using vibratory stimulation has various drawbacks, including potential stress development caused by prolonged stimulation [4]. Thermal perception plays an important role in human activity [5] and affects emotion, sentiment, and pleasantness [3]; thus, a communication device that has an effective interface with humans by using thermal perception is favorable [6].

Akiyama et al. [3] observed changes in emotional states by presenting thermal stimuli along with music as auditory stimuli. They compared subjective feelings of

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emotional states by using two conditions: whether the thermal stimuli are controlled by a designated thermal profile given during music appreciation programs. However, relevant studies show a lack of objective evaluation of emotional changes because most have focused on estimating changes in emotional states subjectively.

In our study, we measured skin conductance responses (SCRs) by using an index for changes, developed by the automatic nerves system that is triggered by thermal stimuli. A change in the SCR amplitude has been regarded as an objective index for emotional changes [7–9]. According to physiological studies [10], SCRs have been considered as an index for resulting in the sweat gland activity, which is controlled by the sympathetic nerves and becomes active when a human perceives a stimulus [11–13]. Thus, the emotion caused by thermal stimulation can be evaluated objectively. Furthermore, estimating the smallest quantity of stimulus required for evoking emotion is possible by clarifying the relationship between the characteristics of thermal stimuli and the SCRs. The results of this study will contribute to the development of a video interface with a more realistic impression by supplemental thermal information.

According to Kenshalo [14], skin temperature, thermal stimulation area, and thermal gradients were the factors influential in the thermal perception of males. This paper focuses on thermal gradients because in the practical use of a tactile device with thermal perception, applying thermal stimulation is necessary, considering its benefit to the users and the difficulty in perceiving the thermal stimulation when the stimulation area is small [15].

The empirical results of this study showed emotional changes represented by different thermal gradients by measuring SCRs when providing thermal information with various thermal gradients.

2 Methods

2.1 Participants

The participants included five college students (with an average age of 22.2 years). All the participants were right handed. Each participant gave written informed consent prior to the beginning of the study.

2.2 Experimental Apparatus

SCRs were measured using a portable bio-amplifier (Polymate, AP1000, NIHON-SANTEKU Co., Japan) with an electrodermal activity (EDA) measurement unit (AP-U30m, NIHONSANTEKU Co., Japan). A thermal stimulator (Intercross-210, Intercross Co., Japan) was used for presenting thermal stimuli. Figure 1 shows the experimental system setup.

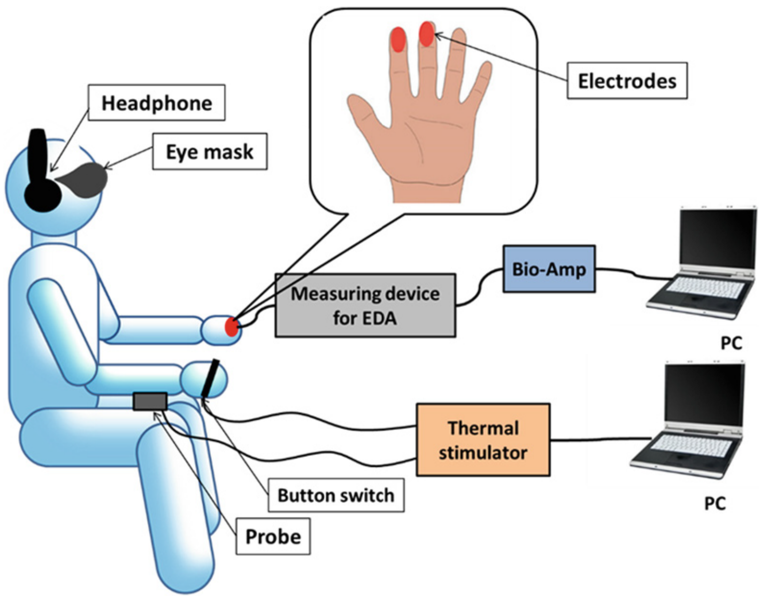

Fig. 1. The experiment system

2.3 Experimental Procedure

As an experimental preparation, participants grasped a button-switch in their right hand, and a probe was attached to their right forearms for providing thermal stimulations. Electrodes (PPS-EDA, TEAC Co.) were attached at the ventral part of the second and third fingers of their left hand for the EDA measurement. All the participants underwent a practice session to learn to press the button-switch as soon as they perceived a temperature change from their thermoneutral state. The thermal gradient was set to 5 levels (−0.5, −0.3, 0, +0.3, +0.5 [°C/s]). Five measurements were performed for each thermal gradient, yielding 25 trials for each participant. The participants used eye masks and headphones to prevent interference with auditory and visual information. The probe and skin temperatures were adjusted to be equal before each trial. Figure 2 shows the diagrammatical view of the temperature adjustment for the coupled areas.

The experimental procedure was as follows.

1. After the practice session, the experiment was started by pre-adjusting the temperature at the probe and skin.
2. The temperature was varied using a designated thermal gradient. Participants pressed the button-switch as soon as they perceived the difference in temperature.
3. Participants filled in a questionnaire regarding the thermal change.
4. Participants took a 1-min break for minimizing the influence of the prior trial.
5. The session ended after 25 repetitions of procedures 2–4.

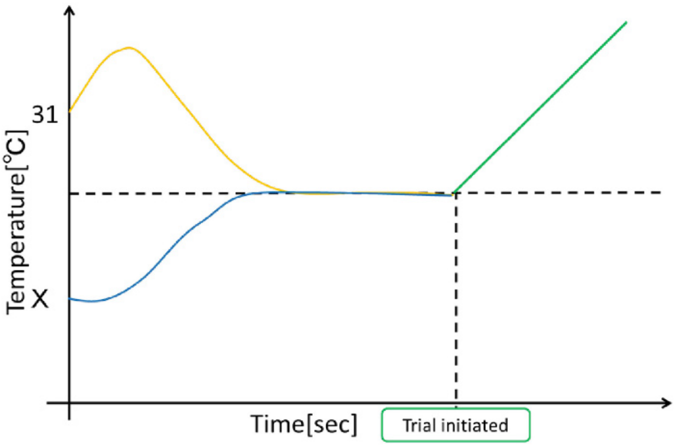

Fig. 2. Temporal changes in the temperature at the probe and the skin. Thermal stimulator was controlled such that the temperature at the probe and the skin was adjusted to be equal before the trial started. (Color figure online)

In addition, the thermal stimulation was stopped when the skin temperature of the participants reached to $\pm$ 5 [°C] from their initial temperature if the participants did not respond. In the case of 0 [°C/s], the participants mostly did not respond; thus, the measurement was terminated after 15 s.

2.4 Data Analysis

Regarding the time of motor responses to the thermal stimuli, Harrison et al. [16] reported the time from the onset of the stimulus to that of the reaction. According to them, the reaction time for the neural processing and reaction for the stimulus was estimated at 0.2 [s], and the distance between the area of stimulus presentation and the spinous process of the seventh cervical vertebra was estimated at approximately 1 [m]. These estimations yielded 2.2 [s] for the overall reaction time, assuming the transmission velocity of C-fibers.

Therefore, the perception time of temperature change was set to 0.2 [s], deducting from the time the participants responded using the button-switch. Figure 3 shows the time flow during the trial where participants perceived the thermal stimuli.

The SCR amplitude was analyzed by referencing two preceding studies, that is, a typical peak of SCR amplitude reached a maximum at 6–8 s after stimuli perception [17], and the SCR amplitude was developed within 5 [s] after stimuli perception [18]. Therefore, the peak of SCR amplitude was defined as the reaction that appeared within 5 [s] after the perception time of temperature change, and the highest peak value within 10 [s] was represented as the amplitude value. Figure 4 shows the diagrammatical view of the analysis regarding the choice of the SCR amplitude value.

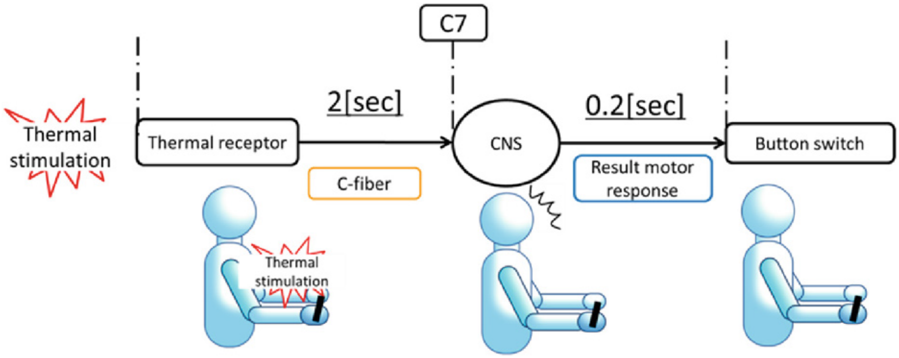

Fig. 3. Time flow of a trial

The perception time of the temperature change and the SCR amplitude were tested for effects due to thermal gradients. The independent variables consisted of the five levels of thermal gradients, whereas the dependent variables comprised the perception time of temperature change and the SCR amplitude. A repeated measures analysis of variance (ANOVA) was performed and a post hoc Bonferroni test was applied if differences existed between thermal gradients.

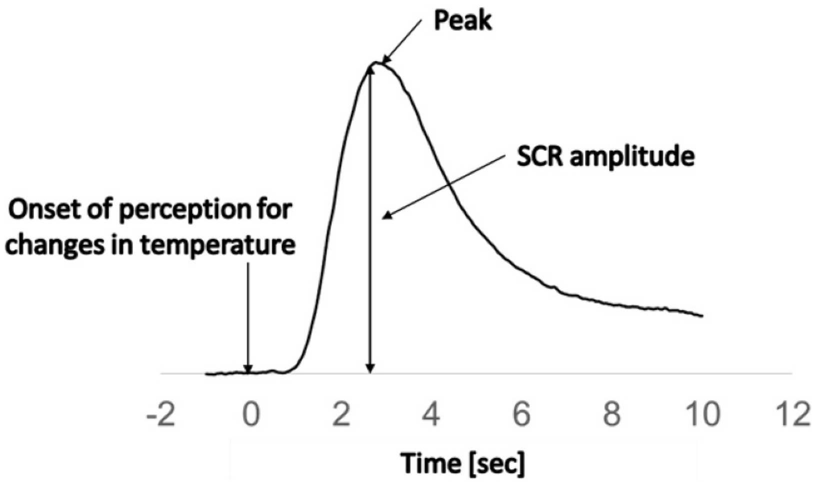

Fig. 4. Determination of peak value for SCR amplitude

3 Results

Figure 5 shows a typical example of SCR obtained in the case of thermal gradient of 0.5 [°C/s]. The solid lines indicate SCR signals, and the dashed lines indicate the time when participants responded.

If the participants failed to respond by the time the trial ended, or no peak values were observed in spite of the response, that trial was not included in the results.

Figure 6 shows the relationship between the thermal gradient and the perception time of temperature change when warm stimuli were applied. Figure 7 shows the relationship between the thermal gradient and the perception time of temperature change when cold stimuli were applied.

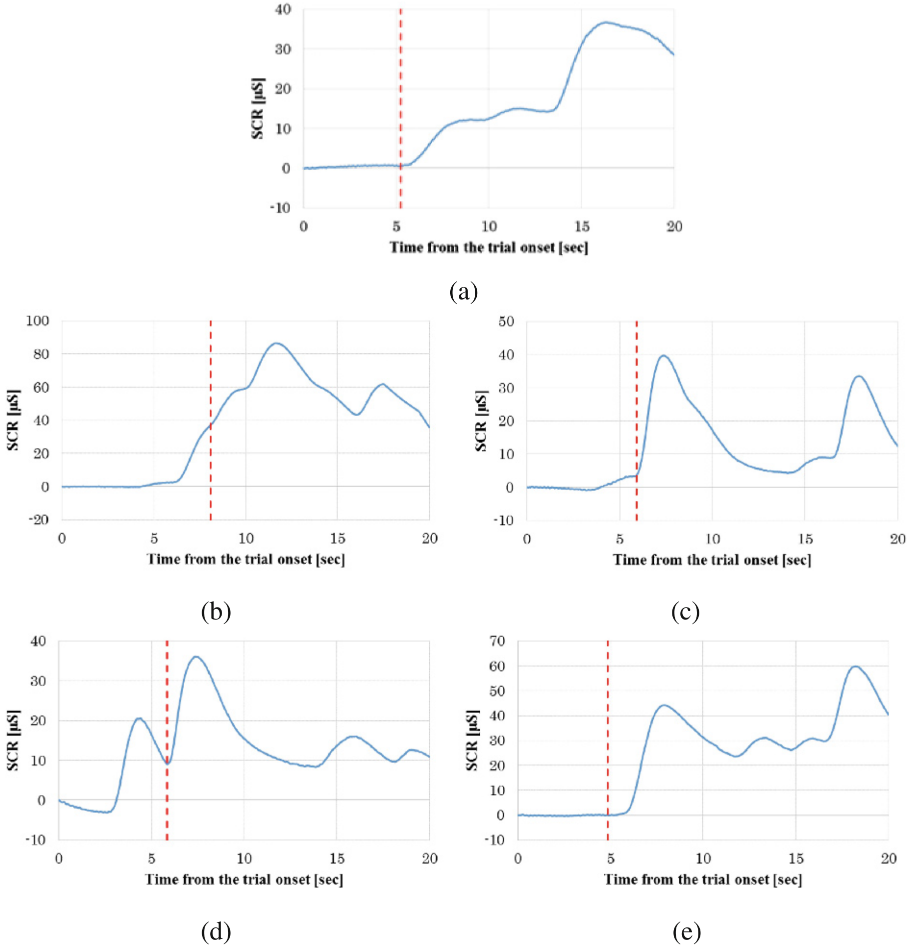

Fig. 5. Measurements of SCR of a certain subject

A significant difference was observed (warm condition: $F(1,48) = 18.35$, $p < .01$; cold condition: $F(1,47) = 31.71$, $p < .01$) as shown in Figs. 6 and 7.

Figure 8 summarizes the standardized SCR amplitudes with the changes in thermal gradients. When the thermal gradient was set to 0 [°C/s], the participants did not respond in all conditions; thus, the SCR value was plotted at 0 [μS] as a reference.

There was a significant tendency ($F(3,87) = 2.95$, $p < .1$) that the SCR amplitude was different between +0.5 and −0.5 [°C/s] and between +0.5 and −0.3 [°C/s] of the thermal gradients.

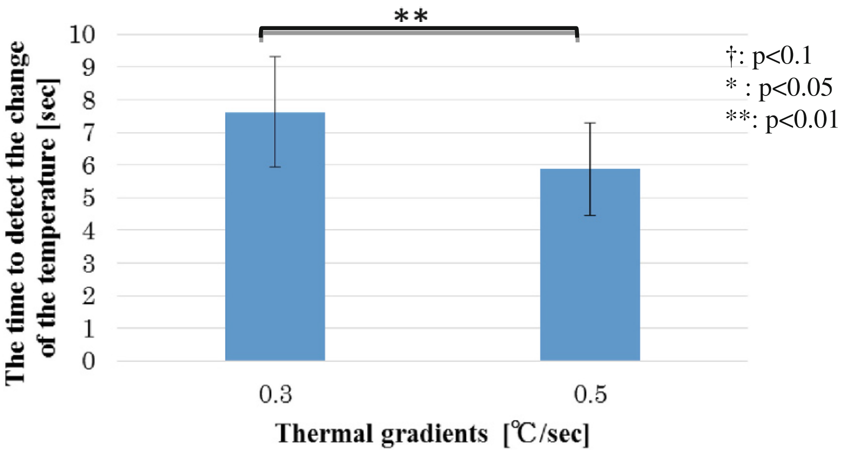

Fig. 6. Relationship between thermal gradients and the time to detect the change of the temperature (warm conditions)

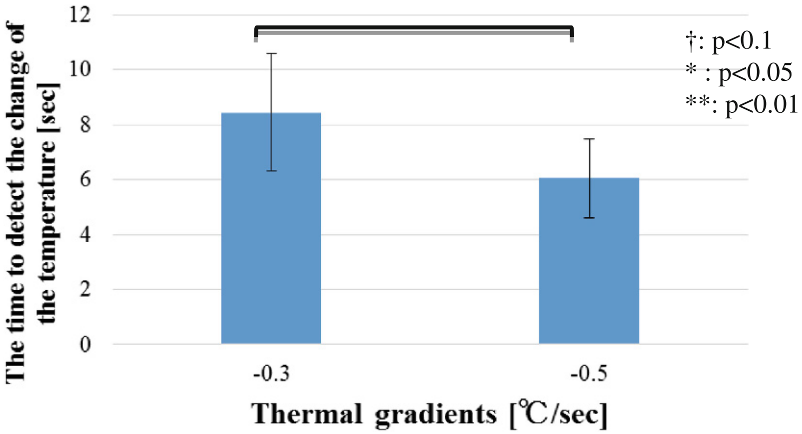

Fig. 7. Relationship between thermal gradients and the time to detect the change of the temperature (cold conditions).

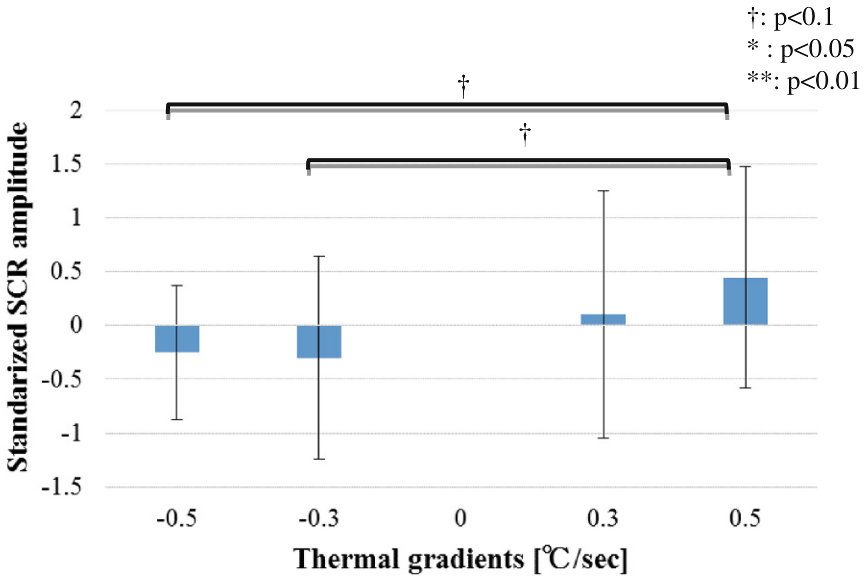

Fig. 8. Relationship between thermal gradients and the normalized SCR amplitudes

4 Discussion

The perception time of temperature change significantly decreased regardless of the stimuli (warm or cold) presented, as the thermal gradients were increased (Figs. 6 and 7). Baba et al. [19] changed the voltage levels applied to a Peltier device to generate different thermal gradients and present various thermal stimuli. They reported that the perception time of temperature change tended to be shorter when thermal gradients were increased. The results of this study are consistent with those of their study. Overall, increasing the thermal gradients was the potential key to the quick perception of temperature change.

ANOVA revealed that a significant difference ($F(3,87) = 2.95$, $p < .05$) in SCR amplitude was present with the difference in the thermal gradients. Therefore, changes in SCR amplitude were due to the difference in the thermal gradients, that is, thermal gradients affected the changes in emotion. Compared to conditions of thermal gradients, the SCR amplitude showed a significant tendency ($p < .1$) to differ when +0.5 or −0.5 [°C/s] and +0.5 or −0.3 [°C/s] of thermal gradients were applied. The results of this study showed that differences in clear thermal gradients, such as the comparison between warm stimuli and cold stimuli, affected emotion, whereas differences in marginal thermal gradients, such as the comparison between 0.3 and 0.5 [°C/s] of thermal gradients, did not show changes in emotion.

Ikeura et al. evaluated psychological changes by using galvanic skin reflex (GSR) when a robot approached participants at different velocity levels [13]. The results of their study suggested that GSR significantly increased when the initial acceleration of the moving robot was high, which differ with the results of our study.

This conflict was due to the modality of perception, that is, the perception mechanism of tactile sensation was different from that of visual information. Humans can perceive changes in a moving object mostly by visual information, whereas they can perceive temperature changes on and off by tactile sensation. Thus, the participants in our study were not sufficiently sensitive to detect the detailed difference in thermal gradients that would cause emotional changes.

Evidence showed that warm stimuli significantly affected emotions compared with cold stimuli. The results reveal that warm stimuli have a potential to offer more clarified information to the users when applying thermal information devices.

5 Conclusions

In this study, thermal stimuli affected emotion, as confirmed by changes in SCR amplitudes. The SCR amplitude had a significant tendency to differ when +0.5 or −.5 [°C/s] and 0.5 or −0.3 [°C/s] of thermal gradients were applied.

This study was limited to interpreting the results regarding the attention level given to the tactile stimuli, that is, the participants were isolated from auditory and visual stimuli and were asked to focus on tactile stimuli. Therefore, the change in SCR amplitudes may arguably be different if the participants were asked to focus on their primary task and the remaining resources were used to detect tactile stimuli. This would be a major consideration for further development of tactile devices.

In the future, we will conduct an experiment evaluating the same procedure with different body parts to determine a body part that may effectively change emotion because of thermal tactile stimuli, instead of the location of the forearm used in this study.

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