Influence on Skin Temperature and Blood Flow of Thermal and Massage Stimuli

H. Inoue and H. Hagiwara, *Member, IEEE*

***Abstract*—Changes in skin temperature are known to be affected by blood flow. The reaction of skin temperature and blood flow when various stimuli are applied to the body has been investigated for many years. However, body reactions when different stimuli are applied concurrently to the body have not been well studied. This study investigated changes in blood flow and skin temperature when massage stimulation and thermal stimulation were applied to the body simultaneously. Skin temperature tended to change quickly when a massage stimulus was present during the task. In addition, the amount of blood flowing values were significantly higher and the speed of blood flow values tended to be higher during tasks with massage stimulus. Massage stimulation thus appears to significantly affect blood flow and accelerate changes in skin temperature from hot and cool stimulations.**

I. Introduction

Changes in skin temperature are known to be affected by blood flow. Various research related to skin temperature and blood flow under various types of stimuli has been undertaken to date.

Previous studies on heating and cooling stimuli have shown that the increase in forearm blood flow that occurs with elevations in body temperature by heating is confined to the skin and superficial tissues [1] and that skin temperature changes more clearly by applying cooling stimulus in comparison with heating stimulus, because the human body has more mechanisms to protect against cold than against heat [2]. In addition, previous studies on external stimuli have shown that peripheral skin blood flow was improved for a given length of time by sponge-bathing peripheral parts of the body while in a bed [3] and that oxy-hemoglobin levels were significantly increased for 10 minutes at the site of pressure stimulation [4]. Such studies have only examined the provision of each stimulus alone. Body reactions to different stimuli applied concomitantly have not been well studied.

The present study therefore investigated changes in blood flow and skin temperature when massage stimulation and thermal stimulation were given to the body at the same time.

H. Inoue is with the Graduate School of Information Science and Engineering, Advanced Information Science and Engineering Major, Human Information Science Course, Ritsumeikan University, 1-1-1 Noji Higashi, Kusatsu, Shiga 525-8577, Japan (e-mail: is005085@ed.ritsumei.ac.jp).

H. Hagiwara is with the Department of Human and Computer Intelligence, College of Information Science and Engineering, Ritsumeikan University, 1-1-1 Noji Higashi, Kusatsu, Shiga 525-8577, Japan (e-mail: hagiwara@ci.ritsumei.ac.jp).

II. Experimental Methods

A. Subjects

Ten healthy, non-medicated subjects (5 men, 5 women; college students; mean age, 21.6 ± 0.49 years; range, 21-22 years) participated in the present study. All subjects refrained from excessive eating and drinking the night before the experiment. In addition, subjects refrained from engaging in prolonged or strenuous exercise before the morning of the experiment. All subjects provided written informed consent prior to participation.

B. Experimental Procedures

The experiment was carried out in an air-conditioned room (temperature: 24-26°C; humidity: 50-65%). All subjects wore the same T-shirt to conform to the experimental conditions. The experiment was performed after skin temperature and blood flow stabilized. Electrodes for skin temperature measurement were attached to subjects at four sites based on the locations of mean skin temperature measurement (ch1: anterior side of upper trapezius; ch2: posterior side of upper trapezius; ch3: mid-trapezius; ch4: nape of neck) [5]. The electrode for blood flow measurement was attached near the ch2 location for measuring skin temperature. Fixation points for the extrudes are shown in Figure 1. After all electrodes were attached, subjects moved to a massage chair (REAL PRO EP-MA 70; Panasonic) and measurement was started. Details of the experimental protocol are shown in Figure 2. In the present experiment, massage stimuli were applied to the shoulder using the massage chair. Stimulus location (shoulder) was detected by the body-sensing function of the massage chair. Body type sensing prevented the misalignment of stimuli due to differences in body type. The experimental procedure included application of a hot massage stimulus and a cool massage stimulus; thermal stimuli were provided by a 5 cm × 5 cm Peltier element. The experiment lasted 30 min (rest: 10 min; task: 10 min; rest: 10 min). During the rest period, subjects sat quietly in the massage chair doing nothing. At the end of the experiment, subjects moved to an office chair and rested until skin temperature and blood flow stabilized. This also served to prevent skin temperature rises in parts of the body touching the massage chair. The experiment was then repeated with a different stimulus. When heat massage stimulus was used in Task 1, Task 2 used cool massage stimulus and when cool massage stimulus was used in Task 1, Task 2 used heat massage stimulus. The experiment was then repeated with another

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stimulus. Thermal stimuli were applied to the anterior side of the upper trapezius near ch1. Temperatures for the hot and cool stimuli were 50°C and 20°C, respectively. Heat stimulus temperature was the same as used in previous studies [6]. Cool stimuli cause a persistent sensation of cold at ≤30°C and cause cold pain at ≤17°C. Cool stimulus temperature was thus set at 20°C to cause a persistent sensation of cold, but not cold pain [7].

In addition to the experiment described above, an experiment was also performed in which only hot and cool stimuli were applied. The two experiments were performed on two separate days to avoid any inter-experiment effects. The order of tasks was randomized to eliminate any order effect.

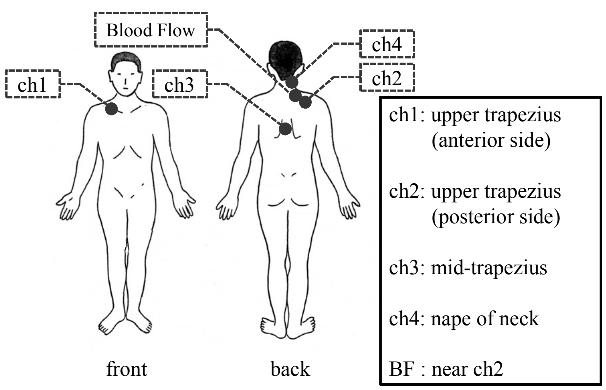

Fig. 1. Electrode fixation points for skin temperature and blood flow.

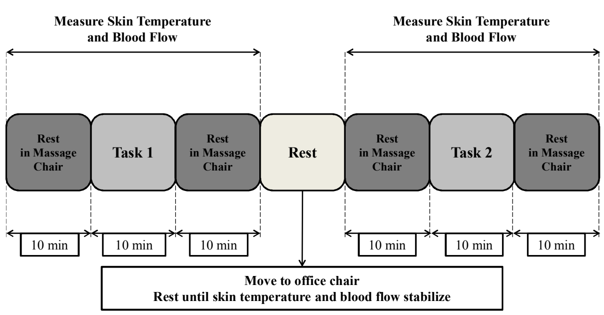

Fig. 2. Details of the experimental protocol

III. Analytical Method

A. Skin Temperature

Skin temperature was measured using a handled thermometer (LT-8A; Gram Corporation) and thermistors (LT-ST08-12, Gram Corporation). The sampling frequency was 1 Hz and measurement locations were the four sites described above. Raw, unfiltered skin temperature was used.

B. Blood Flow

In the present experiment, blood flow was measured from the laser Doppler flowmetry (FLO-C1; OMEGA WAVE) and a probe (Type DS Disc Shape; OMEGA WAVE). The mechanics of blood flow measurement are as follows. The tissue at the measurement site is irradiated by laser light through the optical fiber probe and the light is scattered numerous times in the tissue. The light that hits the flowing blood changes frequency according to the speed of blood flow. On the other hand, the light that hits stagnant blood does not change frequency. Some such light is captured by the light-receiving fiber, and is measured by the laser Doppler blood flow meter. The magnitude of the frequency modulation of light corresponds to the speed of blood flow (VELOCITY) and the intensity of the light corresponds to the amount of blood flowing (MASS). The amount of modulated light received increases as the amount of blood flow increases. The product of these two parameters (VELOCITY and MASS) corresponds to tissue blood flow (FLOW). Analysis parameters targeted MASS and VELOCITY comprising FLOW in the present experiment. All measurement parameters were filtered (0.003 Hz) and noise was eliminated using a digital low-pass filter made with MATLAB (MathWorks).

IV. Results

A. Skin Temperature

Figure 3 shows mean skin temperature for all subjects during each procedure. Task period is from 10 to 20 minutes. As shown, skin temperature measured at ch1, where the thermal stimulus was applied, changed significantly during tasks (from 10 to 20 min). Skin temperature tended to change quickly when massage stimulus was present during the task. In addition, the ch3 mid-trapezius site showed characteristic changes when thermal massage stimulus was applied. Figure 4 shows the variation in skin temperature at ch1 when thermal stimulus alone and thermal massage stimulus were applied. Comparing tasks with and without massage stimulus, variation in skin temperature from the hot stimulus was greater than that from the hot massage stimulus, and variation in the skin temperature from the cool massage stimulus was greater than that from the cool stimulus. Figure 5 shows variations in skin temperature at ch2 when thermal stimulus alone and thermal massage stimulus were applied. Comparing tasks with and without massage stimulus, variation in skin temperature during the task from hot stimulus was significantly greater ($p < 0.05$) than that from hot massage stimulus, and variation in skin temperature during the task from cool stimulus was greater than that from cool massage stimulus.

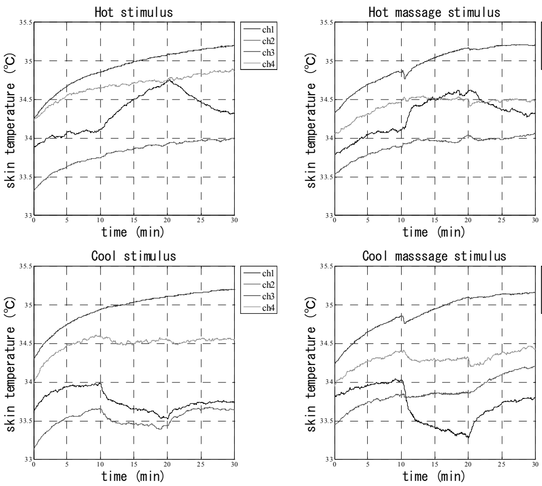

Fig. 3. Mean skin temperature for all subjects in each task. Task period is from 10 to 20 minutes.

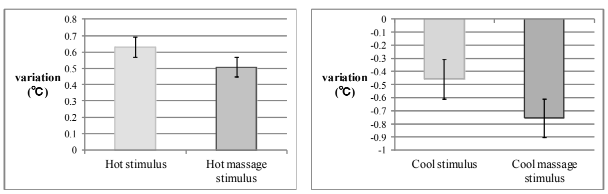

Fig. 4. Variations in skin temperature at ch1 during tasks with thermal stimulus alone and with thermal massage stimulus. Left) With hot stimulus. Right) With cool stimulus. The vertical lines are standard deviation.

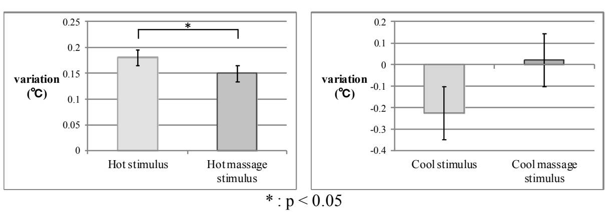

Fig. 5. Variations in skin temperature at ch2 during tasks with thermal stimulus alone and with thermal massage stimulus. Left) With hot stimulus. Right) With cool stimulus. The vertical lines are standard deviation.

B. Amount of Blood Flow (MASS)

Figure 6 shows mean MASS for each task. These values were divided into 10-min periods and the values from the first and last 1 min of each period were excluded to remove noise caused by change in body position. MASS values were significantly higher ($p < 0.05$) during tasks with massage stimulus. Little change in MASS values was seen during tasks with thermal stimulus alone. Figure 7 shows temporal variations in skin temperature at ch1 and MASS values. When MASS values were high, skin temperature changed significantly. On the other hand, there were few changes in MASS, and the change in slope of skin temperature was small.

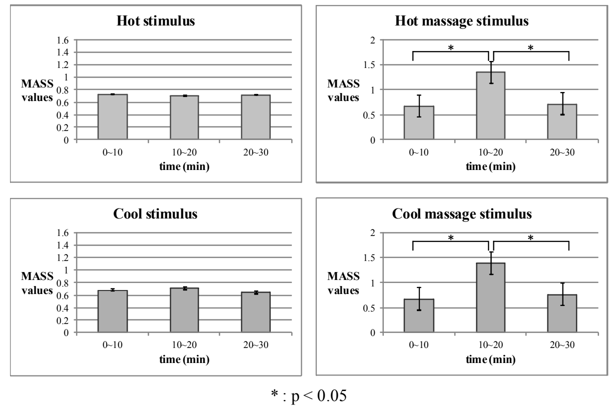

Fig. 6. Mean values of MASS for each task. Data were divided into 10-min periods and the first and last 1 min of each period were excluded. The vertical lines are standard deviation.

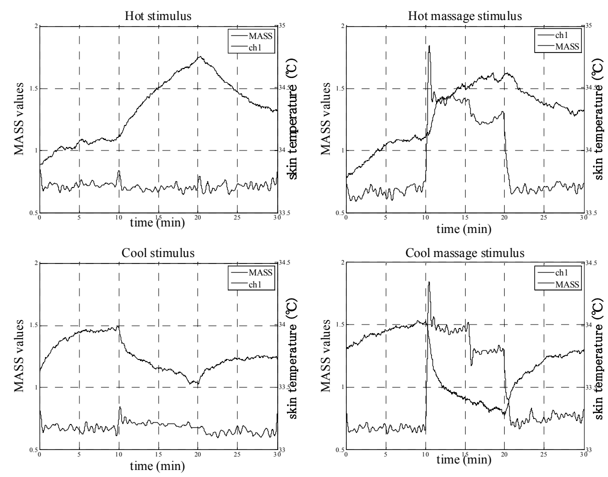

Fig. 7. Temporal variations in skin temperature at ch1 and MASS for each task. Task period is from 10 to 20 minutes.

C. Speed of Blood Flow (VELOCITY)

Figure 8 shows mean VELOCITY in each task. These values were divided into 10-min periods and the values from the first and last 1 min of each period were excluded to remove noise caused by change in body position. VELOCITY values tended to be higher during tasks with massage stimulus, but almost no variations were seen during tasks without massage stimulus.

V. Discussion

We investigated changes in blood flow and skin temperature when four different stimuli (hot stimulus, hot massage stimulus, cool stimulus, cool massage stimulus) were applied.

The results showed that skin temperature tended to change quickly during application of massage stimulus. A similar tendency was observed in previous studies [6, 8]. Massage stimulus thus can be considered an effective way to accelerate changes in skin temperature. Variations in skin temperature

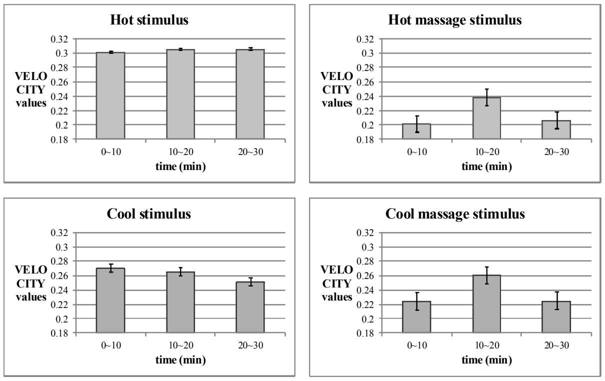

Fig. 8. Mean values of VELOCITY for each task. Data were divided into 10-min periods and the first and last 1 min of each period were excluded. The vertical lines are standard deviation.

from the hot stimulus were greater than those from the hot massage stimulus, and variations in skin temperature from cool massage stimulus were greater than those from cool stimulus. For hot stimulus, the skin temperature of other regions changed with the massage stimulus task. In addition, the mid-trapezius area of ch3 showed characteristic changes with thermal massage stimulus. Massage stimulus thus appears to spread hot stimulation to other parts of the body. On the other hand, for cool stimulus, a previous study showed that the human body is more protective against cold than heat [2]. Therefore, when skin temperature was decreased markedly by cool massage stimulus, the significant reaction observed was likely an exaggerated response of the body.

For blood flow, MASS values were significantly higher during tasks with massage stimulus. However, little change was seen during tasks with thermal stimulus alone. Massage stimulus thus has a substantial effect on MASS. In addition, there was a large change in slope of skin temperature when MASS values were high. The change in MASS values appears to affect the speed of changes in skin temperature by hot and cool stimulation. VELOCITY values tended to be higher during tasks with massage stimulus, although no significant difference in VELOCITY values was seen with or without massage stimuli. It is believed to be the effect of the differences in initial VELOCITY values among subjects at the measurement starting point. A future challenge is to achieve a similar initial VELOCITY value among subjects.

VI. Conclusion

The present study investigated changes in blood flow and skin temperature when four different stimuli (hot stimulus, hot massage stimulus, cool stimulus, cool massage stimulus) were applied. The results suggest that thermal massage stimulus significantly affects MASS and there was a large change in slope of skin temperature. Therefore it is assumed that the change in MASS values affects the speed of changes in skin temperature by hot and cool stimulation. VELOCITY values tended to be higher during tasks with the massage stimulus, but no significant difference was seen with or without massage stimuli. A future challenge is to achieve a similar initial VELOCITY value among subjects.

Acknowledgment

This study was supported by a research grant (Grant-in-Aid for Scientific Research (C), No. 22500415) from an independent administrative institution, the Japan Society for the Promotion of Science.

References

[1] O. G. Edholm, R. H. Fox, R. K. Macpherson, "The effect of body heating on the circulation in skin and muscle," *The Journal of Physiology*, vol.134(3), pp. 612-619, 1956 December 28.

[2] C. Huizenga, H. Zhang, E. Arens, D. Wang, "Skin and core temperature response to partial- and whole-body heating and cooling," *Journal of Thermal Biology*, vol. 29, pp. 549-558, 2004.

[3] S. Sudo, K. Aoki, M. Tomioka, R. Masago, T. Matsuda, "Pressure Difference on the Cleansing of Bed Bath in the Limbs Alters the Peripheral Skin Blood Flow Responses," *Japan Society of Nursing Research*, vol. 31(1), pp. 121-128, 2008.

[4] H. Matsuoka, T. Nakamura, "Effects of pressure stimulation at a site hemodynamically close to human forearms," *Journal of the Japan Society of Acupuncture and Moxibustion*, vol. 60(1), pp. 48-53, 2010.

[5] K. Kuwabara, T. Mochida, K. Nagano, K. Shimakura, "Fundamental Study of Weighting Factor for Calculating Mean Skin Temperature," *Journal of Human and Living Environment*, vol. 8, pp. 33-40, 2001.

[6] H. Inoue, H. Hagiwara, "Influence on Skin Temperature and Blood Flow by Local Thermal Massage Stimuli," *Proceedings of the 27th Symposium on Biological and Physiological Engineering*, pp. 26, 2012.

[7] R. F. Schmidt, "Memorix Spezial Physiologic," *IGAKU-SHOIN Ltd.*, pp. 80-81, 1997.

[8] H. Inoue, H. Hagiwara, "Influence on Skin Temperature and Blood Flow by Local Thermomassage," *The Japanese Journal of Ergonomics*, vol. 48, pp. 376-377, 2012.