EFFECTS OF LOWER BODY WARMING ON PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSES OF HUMANS

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INTRODUCTION

Vertical temperature differences exist in our daily thermal environment, and ISO and ASHRAE suggests that the temperature of the lowest level of air (at foot height) should not be lower than that at the head. During the winter season in Japan, a heater aimed at warming the lower body, known as a "Kotatsu," is commonly used, so Japanese are often exposed to great differences in vertical temperature. In this study, we conducted subjective experiments to investigate the effects of lower body warming on physiological and psychological responses of human subjects.

METHODS

Experimental Conditions and Measured Items

The experiments were conducted in a climate chamber at Kyushu University. An air-conditioning box (AC box) was installed in the chamber, and the inside temperature of the box (Tbox) was set and kept separately from the temperature of the rest of the climate chamber. The temperature of the climate chamber was set at 14ºC, and that of the Tbox was set at 14 ºC, 23 ºC, 32 ºC, 41 ºC, or 50ºC. The subjects were 8 healthy Japanese male university students. Physiological response was assessed by measuring the skin temperature, rectal temperature, blood pressure, heart rate, ECG for analysis of heart rate variability (HRV), salivary Ig-A, and cortisol concentration. We also asked for subjective responses regarding thermal sensation, thermal comfort, and fatigue including sleepiness. Subjects performed a Sternberg memory search task on a PC for 20 minutes while sitting in the AC box. Figure 1 shows a sketch of the AC box.

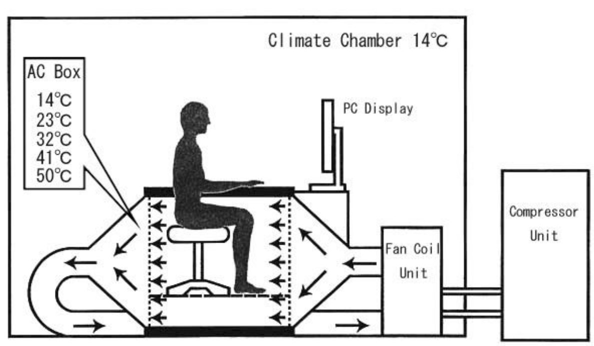

Figure 1. Sketch of the air-conditioning box

Experimental Protocol

Subjects sat on a chair in the AC box for 90 minutes. During the experiments subjects wore 0.7 clo clothes and remained seated. Figure 2 shows the experimental protocol and measurement items.

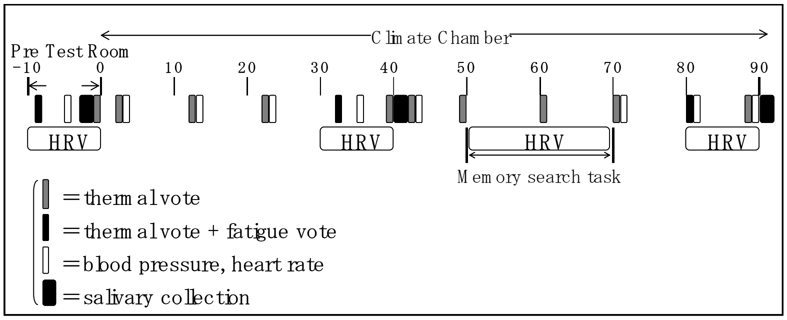

Figure 2. Experimental protocol and measurement items

RESULTS AND DISCUSSION

Distribution of the Skin and Rectal Temperature

Figure 3 shows the distribution of the skin and rectal temperature after 90 minutes of exposure. The mean skin temperature was calculated using the Hardy & DuBois 12-point formula. Each subject's forehead, chest, back, upper arm, back of hand, and finger were exposed to the 14ºC ambient temperature, and the thigh, shins, calf, foot, and toe were kept inside of the AC box and exposed to the target temperature, Tbox. The higher the Tbox was, the higher the distal temperature both in hands and legs.

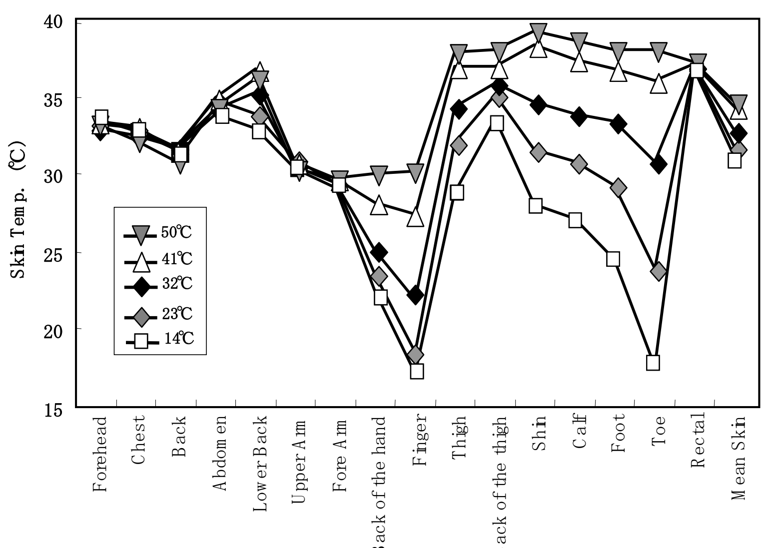

Figure 3. Distribution of the skin temperatures

Changes in the Cortisol Concentration

Figure 4 shows the time courses of mean cortisol concentration. When Tbox was 14ºC, 23ºC, or 32ºC, the cortisol concentration decreased gradually, but when Tbox was 41ºC or 50ºC, the cortisol concentration did not decrease. Two-way analysis of variance revealed a significant main effect of time, but there were no significant differences in Tbox and interaction of Tbox and time.

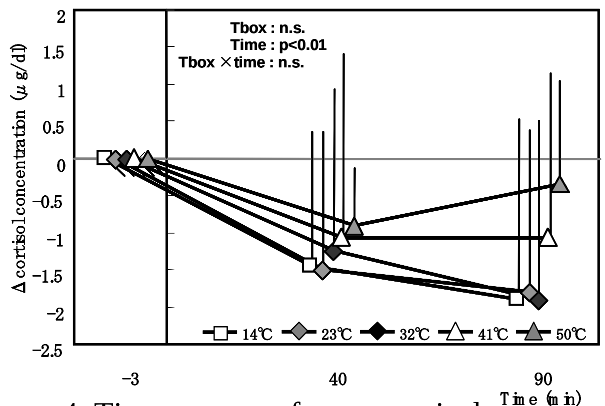

Figure 4. Time courses of mean cortisol concentration

Results of Memory Search Task and Fatigue Vote

Figure 5 shows the mean of the total numbers of correct answers in the Sternberg memory search task performed for about 20 minutes. There were no significant differences in Tbox, but compared to the other conditions, the mean value was slightly smaller when Tbox was 50ºC. Figure 6 shows the time courses of the mean score of sleepiness. Two-way analysis of variance revealed a significant main effect of time, but there were no significant differences in the interaction of Tbox and time. Compared with when Tbox was 14ºC or 23ºC, the sleepiness score was higher when Tbox was 32 ºC, 41 ºC, or 50ºC after 20 minutes of exposure.

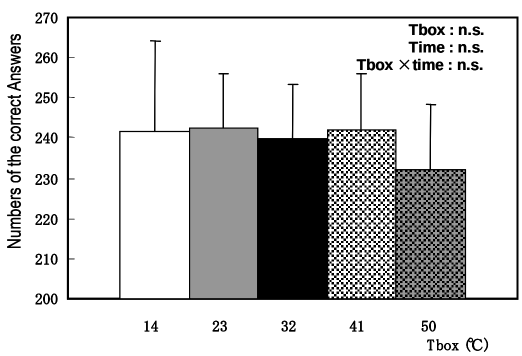

Fig. 5. Correct Answers in the Memory Search Task

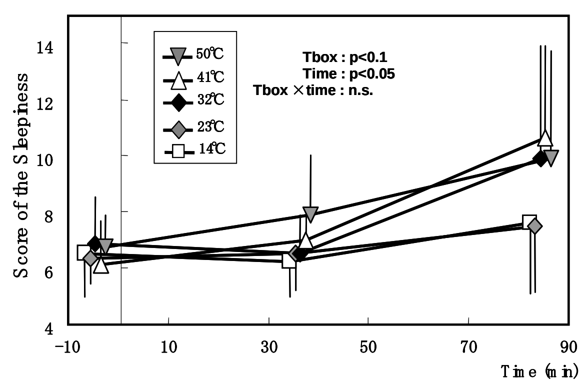

Fig. 6. Mean Score of Sleepiness

Thermal Sensation and Comfort

Figure 7 shows the relationship between Tbox and subjective vote after 90 minutes of exposure. The higher the Tbox became, the higher the thermal sensation votes were. Based on the correlation between Tbox and thermal sensation, the neutral thermal vote was given when the Tbox was 38.1ºC. Also, based on the relationship between the Tbox and thermal comfort vote, the maximum comfort vote was given when the Tbox was 35.6ºC. When the Tbox was 32 ºC or 41ºC, the mean skin temperature was approximately 33-34ºC (Figure 3). Therefore, even though a vertical ambient temperature difference existed, the thermal neutral vote was given when the mean skin temperature was approximately 33-34ºC..

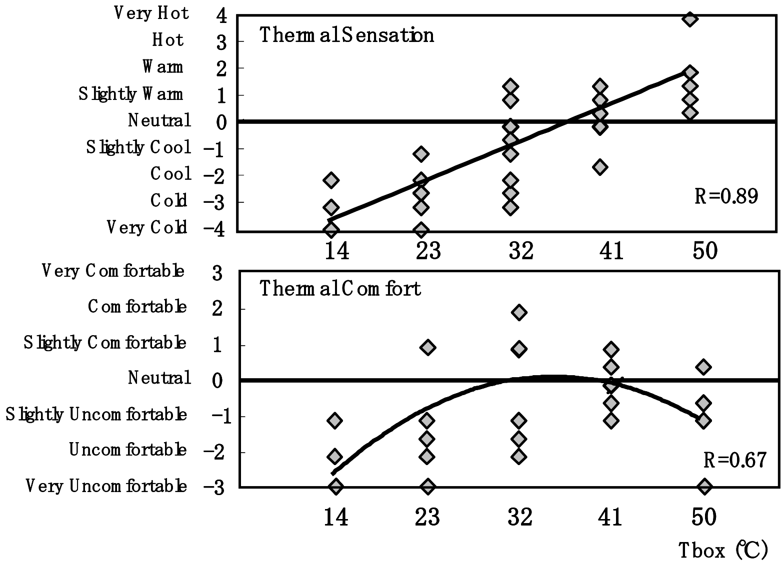

Figure 7. The relationship between Tbox and subjective vote.

Comparison with Previous Studies

To compare our findings with the data of previous studies on vertical thermal comfort, we formulated the weighted ambient-box temperature (Twab), which was defined as follows:

$$Twab = \text{Upper ambient temperature} * 0.488 + \text{Lower box temperature} * 0.512$$

The coefficient values, 0.488 and 0.512, were calculated from the data of Japanese upper and lower body surface area, respectively (Kurazumi et al, 1994).

Figure 8 shows the relationship between Twab and subjective votes. In all studies, similar distributions are seen and the neutral thermal sensation is given in the Twab of 23-26ºC respectively. In the same way, maximum thermal comfort votes are given when the Twab is between 24 ºC and 25ºC, approximately.

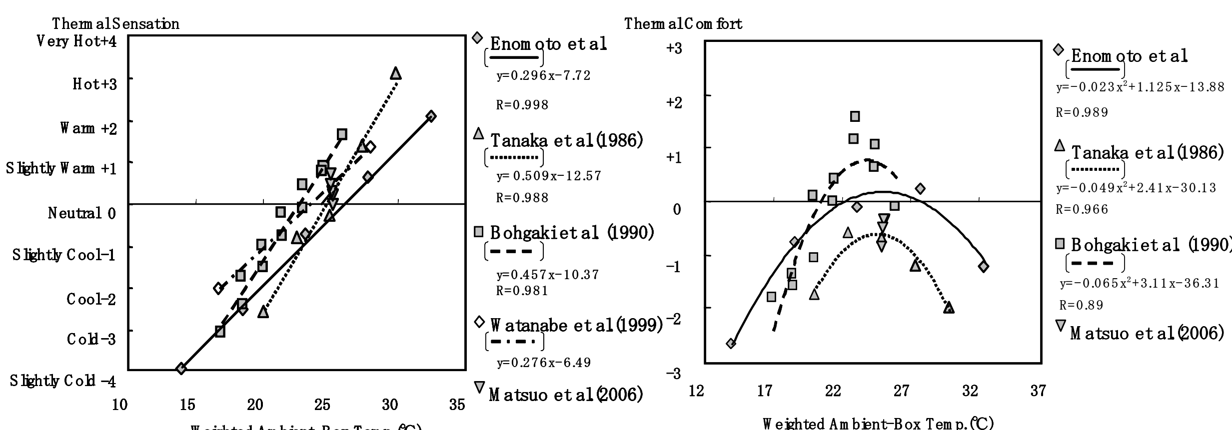

Figure 8. The relationship between Twab and subjective votes in previous studies and the current study

CONCLUSIONS

1. Within the experimental conditions in this study, Tbox should be between 32ºC and 38 ºC for best thermal comfort and physiological responses.
2. We defined the Twab, and in both previous studies and the current study, optimum conditions are given when the Twab is 24-25ºC

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