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ORIGINAL PAPER

Effect of change in ambient temperature on core temperature of female subjects during the daytime and its sex differences

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Abstract

Tympanic temperature (T_{ty}), skin temperature, and regional dry heat loss were measured continuously in eight female subjects under three conditions: (1) stepwise increases in ambient temperature (T_a) from 26 °C at 09:00 to 30 °C at 18:00, (2) steady T_a at 28 °C from 09:00 to 18:00, and (3) stepwise decreases in T_a from 30 °C at 09:00 to 26 °C at 18:00. Oxygen consumption, body weight loss, thermal sensation, and comfort levels were periodically recorded. The T_{ty} increased significantly ($p < 0.01$) from 36.1 ± 0.36 °C to 36.6 ± 0.23 °C at 18:00 under condition 1 but remained virtually unchanged under conditions 2 and 3. Thermal comfort was observed at 15:00 and 17:00 under condition 3, whereas subjects reported that they felt slightly cool at 15:00. The rate of body heat storage (S), changes in T_{ty}, mean skin temperature ($\overline{T}_{sk}$), and mean body temperature during each period were calculated, and confirmed that changes in $\overline{T}_{sk}$ was correlated with S. Diurnal changes in core temperature (T_c) appeared to be more dependent on diurnal rhythm than on changes in T_a, except when T_a increased continuously. Thus, it may be difficult to predict diurnal changes in women's T_c using a body-heat-balance equation during thermal transient.

Keywords Diurnal change in core temperature · Sex difference · Skin temperature · Thermal comfort

Introduction

Sex differences in thermal regulation have long been recognized. For example, Morimoto et al. (1967) reported the physiological responses of female subjects in the early follicular phase and male during exposure to warm and hot conditions. The results demonstrated that sweating rates were significantly lower in female subjects than in male subjects under warm conditions; this difference became greater under hot conditions. Similarly, Inoue et al. (2000) reported that heat loss may be more dependent on vasodilation than on sweating in female subjects exposed to 30 °C and 45% relative humidity (RH) while their feet were heated with a hot water bath (42 °C). They suggested that female athletes may have a thermoregulation deficiency in their performance under hot conditions. On the other hand, Schwiening et al. (2011) recently demonstrated no gender difference in sweat output and sweat rate.

Stevens et al. (1987) reported that cold lowered skin temperature more in women than in men but observed no differences in heart rate, stroke volume, or oxygen consumption at 5 °C or 21 °C in women. Wagner and Horvath (1985) conducted experiments with young and relatively old human subjects of both sexes and reported that older women maintained a constant rectal temperature at a greater metabolic cost than did men or younger women, despite the greater availability of insulation from body fat. These studies indicate that significant decreases in skin temperature due to higher body fat may be expected in female subjects, particularly older women. Kakitsuba and Mekjavic (2018) recently tested sex differences in the core interthreshold zone (CIZ) in young male and female subjects whose adiposity levels were relatively low. The results demonstrated no significant sex difference or diurnal variation in the CIZ, and a continuous increase in the CIZ from morning until evening in both men and women under a normal core temperature (T_c) circadian rhythm. These studies imply that morphology may be an important factor related to sex difference in thermal regulation during cold exposure.

Sex differences in temperature perception have recently been studied. For example, Ciuha and Mekjavic (2016) studied regional thermal comfort zones in males and females and

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reported that the range of regulated temperatures did not differ between sexes or skin regions. Ciuha and Mekjavic (2017) compared the thermal comfort zones of the hands, feet, and head in eight male and eight female participants, assessed using water-perfused segments. They reported that the range of regulated temperature did not differ between tested skin regions or between sexes when exposed to normothermic conditions. However, Golja et al. (2003) evaluated the reproducibility of forearm threshold measurements for warm and cold sensation, and their dependence on sex. The results demonstrated that females were more sensitive to thermal stimulation than males.

Sex differences in psychological and physiological responses in indoor environments have also been studied recently (e.g., Maykot et al. 2018; Gerrett et al. 2015; Xiong et al. 2015; and Karjalainen 2007). Liu et al. (2018) reported that females were less satisfied with room temperatures than were males, preferring higher room temperatures. Schellena et al. (2012) reported that local sensations and skin temperatures of the extremities had a significant influence on whole body thermal sensation in women. Ugursal and Culp (2013) demonstrated that females consistently felt warmer and more uncomfortable than males under the same thermal conditions, and that thermally neutral temperatures, perceived as neither cool nor warm, were 26.4 °C for males and 23.9 °C for females. These studies imply that sex differences regarding thermal comfort may be dependent largely on individual preference.

It is well recognized that no physiological functions maintain diurnal rhythms in T_c during the day. In contrast, physiological functions before and during nocturnal sleep, such as melatonin secretion, induce a decrease in T_c for smooth transition to sleep (Shanahan and Czeisler 1984). Therefore, thermal environments should be controlled carefully during the daytime to ensure thermal comfort or reduce thermal stress. To determine how changes in T_c reflect imbalances between heat production and heat loss in a daily rhythm while ambient temperature (T_a) changes during the daytime, Kakitsuba and White (2013) assessed physiological and psychological responses of the male subjects under three different ambient conditions. They hypothesized that a continuous increase in T_a from the morning to the afternoon would lead to improved physiological and psychological responses relative to either a steady state of T_a at 28 °C or a continuous decrease in T_a over the same period. The results demonstrated that diurnal rhythm of T_c controlled T_a in the morning; however, changes in T_a controlled T_c in the afternoon and evening. Thus, the body-heat-balance equation, which is based on the relationship between a change in mean body temperature and the rate of body heat storage, can be applied only in the afternoon and evening.

Considering that diurnal rhythm of T_c may be a determinant factor in thermal regulation that differs by sex, sex differences in psychological and physiological responses were demonstrated by reproducing the experiments of Kakitsuba and White (2013) but with female subjects, using the same experimental protocol.

Methods

Subjects

Eight young Japanese female subjects with a mean age of 20.8 ± 1.5 years (mean ± standard deviation, SD) volunteered to participate in this study; their physical characteristics are listed in Table 1. Body surface area was calculated using the formula of Kurazumi et al. (1994). All subjects were self-described as susceptible to heat, whereas only two were self-described as susceptible to cold. All subjects provided informed consent to participate in the study and were fully aware that they could withdraw from the study at any time without prejudice. The protocol of the study was approved by the institutional ethics review board of Meijo University.

Experiments were scheduled for the follicular phase of the subjects. To control the circadian rhythm of T_c, subjects were asked to adhere to the following regular daily schedule for the week prior to the experiments: going to sleep at 24:00, waking at 08:00, eating breakfast from 08:00 to 09:00, eating lunch from 12:00 to 13:00, and eating dinner from 18:00 to 19:00.

Experimental protocol

All experiments were conducted in a climatic chamber at Meijo University. Prior to each experimental session, the subjects wore a short-sleeved shirt and shorts with an estimated clothing insulation value of 0.27 clo and went to sleep at 24:00 in the climatic chamber, where T_a was controlled at 28 °C throughout the night. They woke at 07:00, ate a designated breakfast of less than 400 cal before 08:00, and ate a designated lunch of 200 cal at 11:30. Throughout the experimental period from 09:00 to 18:00, the subjects were required to remain quiet on a chair.

RH was set at 60% in the climatic chamber for each condition. Subjects were exposed to three different thermal conditions. Under condition 1, T_a was controlled at 26 °C at 09:00 and increased in a stepwise manner to 30 °C at 18:00 at a rate of 0.44 °C per hour. Under condition 2, T_a was controlled at a steady 28 °C throughout the experimental period, to provide optimal thermal comfort for lightly clothed subjects (Rohles and Nevins 1971). Under condition 3, T_a was controlled at 30 °C at 09:00 and decreased to 26 °C in a stepwise manner until 18:00 at a rate of 0.44 °C per hour. The changes in T_a under all three thermal conditions are shown in Fig. 1.

Considering that T_c changes with the menstrual cycle, the experiment was scheduled before ovulation for each female

Table 1 Physical characteristics of the subjects who participated in this study

Subjects	Age (year)	Height (m)	Weight (kg)	AD (m^2)*	Susceptible to heat	Susceptible to cold
A	22	1.62	63.0	1.67	Yes	Yes
B	21	1.62	51.0	1.54	Yes	Yes
C	21	1.70	56.0	1.65	Yes	No
D	21	1.50	50.0	1.45	Yes	No
E	19	1.48	43.0	1.35	Yes	Yes
F	18	1.54	51.0	1.48	Yes	Yes
G	22	1.57	42.7	1.41	Yes	Yes
H	22	1.47	40.0	1.31	Yes	Yes
Mean ± SD	20.8 ± 1.49	1.56 ± 0.08	49.6 ± 7.63	1.48 ± 0.13		

*AD, body surface are (m^2) was calculated from Kurazumi's formula (1994)

subject. All subjects underwent three trials in a randomized order. To minimize effects of light exposure on diurnal changes in T_{ty}, the lighting in the climatic chamber (height 85 cm) was controlled at 500 lx throughout the experimental period.

Measurements

T_{ty} and skin temperature T_{sk} were monitored at seven sites (forehead, forearm, abdomen, front of thigh, front of shin, back of hand, and back of foot) using thermistors. Recorded values were stored every 10 s using a data logger system (Cadac2 Model 9200A; Cadac, Tokyo, Japan) throughout the experimental period. Mean skin temperature ($\overline{T}_{sk}$) was calculated using Eq. (1) following the method of Hardy and DuBois (1938).

$$\overline{T}_{sk} = 0.07T_1 + 0.14T_2 + 0.35T_3 + 0.19T_4 + T0.13T_5 + 0.05T_6 + 0.07T_7. \quad (1)$$

To estimate the total dry heat loss (H_S), we measured regional dry heat loss from the skin surface using heat flux transducer discs (TM1; Kyoto Denshi Co. Ltd., Kyoto, Japan) at seven sites adjacent to the T_{sk} measurement locations throughout the experimental period. H_S (W/m^2) was then estimated using the following equation.

$$H_S = 0.07H_{S1} + 0.14H_{S2} + 0.35H_{S3} + 0.19H_{S4} + T0.13H_{S5} + 0.05H_{S6} + 0.07H_{S7} \quad (2)$$

Heat loss by sweat evaporation (H_L) was estimated by measuring body weight hourly using a body weight scale (precision: 10.0 g; GP-100 K; A & D Co. Ltd., Tokyo, Japan). H_L (W/m^2) was then calculated as follows.

$$H_L = \Delta \mathrm{Wt} \times \lambda / A_D \quad (3)$$

where ΔWt is weight loss (kg/h), and λ is latent heat (= 2.42 kJ/g).

To estimate heat production (M), oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were monitored using gas analyzers (V2000; S & ME Co., Tokyo, Japan) during designated periods: 09:00–10:00, 13:00–14:00, and

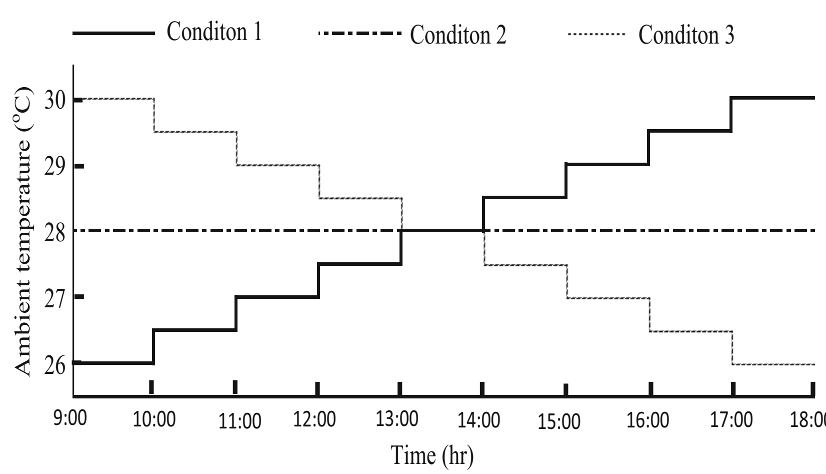

Fig. 1 Changes in ambient temperature (T_a) under three thermal conditions

16:00–17:00. M (W/m^2) was then calculated from the equation (Weir 1949).

$$M = (0.23 \times RQ + 0.77) \times 5.87 \times \dot{V}O_2 \times 60/A_D \qquad (4)$$

where RQ is the respiration quotient ($\dot{V}CO_2/\dot{V}O_2$).

In addition to physiological measurements, we asked subjects to report their perceptions of temperature and comfort on a categorical basis. We used the ASHRAE seven-point scale (Berglund 2001) to assess thermal sensation and the four-point scale to assess thermal comfort (Table 2). Subjects reported their votes at 15-min intervals during four periods: 09:00–10:00, 13:00–14:00, 15:00–16:00, and 17:00–18:00.

Statistical analysis

Mean values of outcome variables were compared by two-way analysis of variance with a repeated-measures design. T_{ty} and $\overline{T}_{sk}$ factors included condition (1, 2, or 3) and time (10-h intervals). Factors in the analyses of relative magnitude of thermal sensation vote (TSV) and thermal comfort vote (TCV), M, H_s, and H_L included condition (1, 2, or 3) and period (09:00–10:00, 13:00–14:00, and 17:00–18:00). Comparisons of significant main effects or interactions among physiological and psychological variables were performed using one-tailed paired t tests. The level of significance was $p < 0.05$, with Bonferroni corrections.

Results

Diurnal changes in T_{ty}

The diurnal changes in T_{ty} under the three tested thermal conditions are shown in Fig. 2. Compared with the nadir times among male subjects reported in previous studies, there was no delay in the nadir among female subjects in this study under any thermal condition. There were significant main effects of time ($F = 172.69$, $p < 0.00005$) and condition ($F = 28.25$, $p < 0.00005$) and a significant interaction between time and condition ($F = 60.03$, $p = 0.0001$), which could be explained by the lower T_{ty} under condition 1 than under conditions 2 and 3 in the morning. Under condition 1, T_{ty} was significantly ($p < 0.01$) lower from 09:10 to 10:30 and significantly higher ($p < 0.05$) from 17:00 to 18:00 than under the other two conditions. Changes in T_{ty} appeared to reflect changes in T_a under condition 1 but not condition 3. Thus, changes in T_{ty} represented a typical T_c circadian rhythm under condition 1.

Table 2 Categories of thermal sensation and thermal comfort votes and their corresponding relative magnitudes of sensation

Thermal sensation vote		Thermal comfort vote	
Hot	+3	Comfortable	0
Warm	+2	Slightly comfortable	−1
Slightly warm	+1	Uncomfortable	−2
Neutral	0	Very uncomfortable	−3
Slightly cool	−1		
Cool	−2		
Cold	−3		

Diurnal changes in T_{sk}

The diurnal changes in $\overline{T}_{sk}$ under the three tested thermal conditions are shown in Fig. 3. There were significant main effects of time ($F = 23.05$, $p = 0.000$) and condition ($F = 52.95$, $p = 0.0000$), and a significant interaction between time and condition ($F = 429.46$, $p = 0.0000$). The interaction could be explained by the lower $\overline{T}_{sk}$ under condition 1 than under the other two conditions in the morning, and a higher $\overline{T}_{sk}$ under condition 1 than under the other two conditions in the late afternoon. Under condition 1, $\overline{T}_{sk}$ was 32.8 °C at 09:00 and continuously increased to 34.4 °C at 18:00, and there was a significant difference ($p < 0.01$) between 09:00–10:30 and 16:30–18:00, which was not observed under conditions 2 and 3.

Body heat balance

The M, H_S, and H_L values for the three thermal conditions during the four observation periods are provided in Table 3. M values were consistent under all conditions at all periods; thus, no significant main effects on M occurred due to time or condition, and there was no significant interaction effect. H_S and H_L changed during the observation period; however, there were no significant main effects of time, condition, or their interaction.

To estimate the effect of heat stress on T_c or mean body temperature ($\overline{T}_b$), the rate of change of T_{ty} ($\dot{T}_{ty}$), the rate of change in $\overline{T}_{sk}$ ($\dot{\overline{T}}_{sk}$), the rate of change in mean body temperature ($\dot{\overline{T}}_b$), and the rate of body heat storage ($S = M - H_S - H_L$; W/m^2) were calculated using the mean values of H_S and H_L during each periods. The $\overline{T}_b$ was calculated using Eq. (5) following the method of Stolwijk and Hardy (1966).

$$\overline{T}_b = 0.9 \times T_{ty} + 0.1 \times \overline{T}_{sk} \qquad (5)$$

The results were indicated in Table 4. Although $\dot{T}_b$ was supposed to be proportionally correlated with S, statistical analyses revealed that both $\dot{\overline{T}}_b$ and $\dot{T}_{ty}$ were not correlated with S in any period but proportionally correlated with $\dot{\overline{T}}_{sk}$ as indicated in Fig. 4.

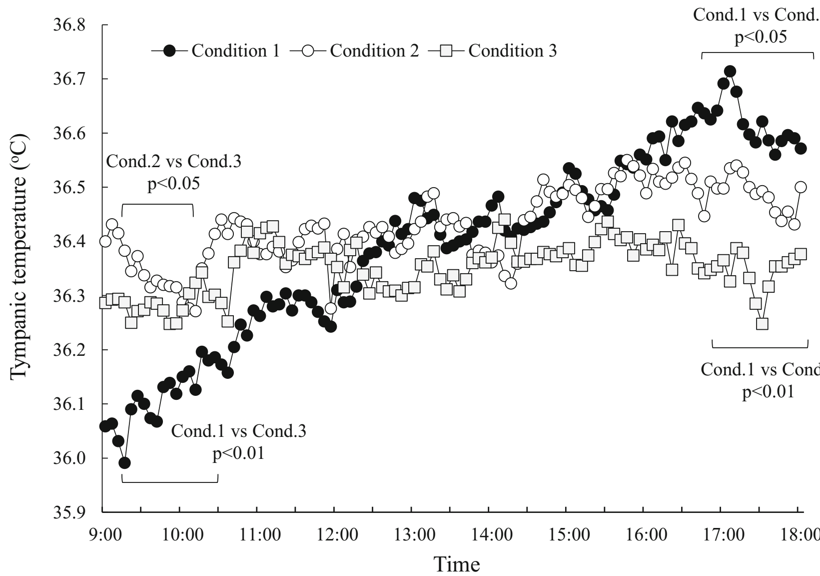

Fig. 2 Diurnal changes in tympanic temperature under three thermal conditions. Under condition 1, tympanic temperature (T_{ty}) was significantly ($p < 0.01$) lower from 09:10 to 10:30 and increased significantly ($p < 0.05$) from 17:00 to 18:00 compared with T_{ty} under the other two conditions. Changes in T_{ty} appeared to reflect changes in ambient temperature under condition 1, but not under condition 3

Psychological responses

The changes in TSV recorded in this study are reported in Fig. 5. There were no main effects of time or condition for TSV, but there was a significant interaction between time and condition ($F = 26.05$, $p < 0.0000$) due to the difference in TSV between the morning and evening under conditions 1 and 3. Although, we expected subjects to be thermally comfortable during all observation periods under condition 2, subjects reported being "slightly warm" from morning to evening. Under condition 1, subjects reported being "slightly cool" in the morning, and then "hot" in the evening. In contrast, subjects reported being "hot" in the morning, and "cool" in the evening under condition 3. As shown in Fig. 5, subjects reported being "hot" in the evening at $\overline{T}_{sk} = 34.6$ °C under condition 1 and in the morning at $\overline{T}_{sk} = 33.7$ °C, which was significantly ($p < 0.01$) lower than $\overline{T}_{sk}$ under conditions 1 and 3.

The changes in TCV are shown in Fig. 6. Under condition 1, subjects reported feeling thermally comfortable in the afternoon, but nearly comfortable in the evening under condition 3. Under condition 2, subjects reported feeling thermally comfortable in the morning and nearly comfortable during all other observation periods. There were no main effects of time or condition on TCV; however, a significant time by condition interaction was detected ($F = 2.78$, $p < 0.00005$) due to a difference in TCV between conditions 1 and 3 in the morning and evening. Post hoc tests showed significant differences between conditions 1 and 3 at 09:00–10:00 ($p = 0.00012$) and 17:00–18:00 ($p = 0.0003$).

Discussion

In this study, eight Japanese female subjects were exposed to identical heat stress by changing T_a between morning and

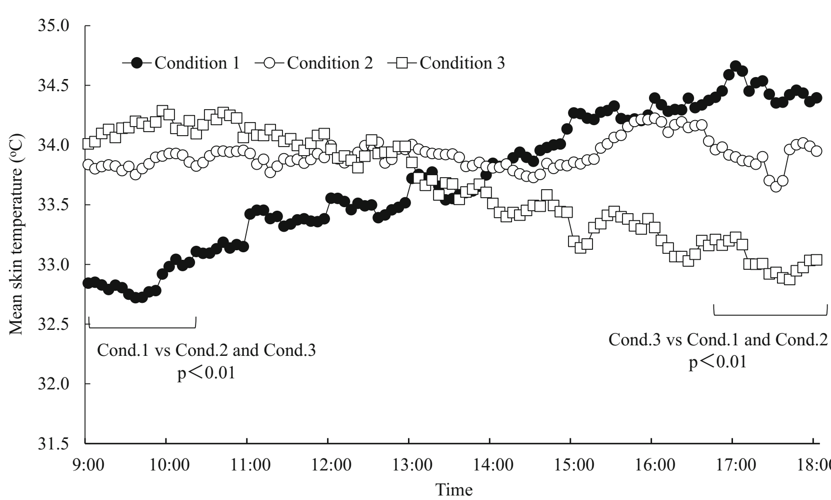

Fig. 3 Diurnal changes in mean skin temperature (T_{sk}) under three thermal conditions. Under condition 1, T_{sk} was significantly ($p < 0.01$) lower from 09:00 to 10:30 and increased significantly ($p < 0.01$) from 16:40 to 18:00 compared with T_{sk} under the other two conditions. Changes in T_{sk} appeared to reflect changes in ambient temperature under all conditions

Table 3 Body heat balance under three thermal conditions

Time period	Heat production and heat loss (W/m2)*	Condition 1	Conditon 2	Condition 3
9:00–10:00	M	47.6 ± 10.1	48.8 ± 14.9	56.0 ± 13.2
	HS	43.8 ± 4.7	36.9 ± 4.7	30.8 ± 5.9
	HL	23.0 ± 7.5	12.2 ± 5.4	9.0 ± 8.9
13:00–14:00	M	51.1 ± 10.6	57.5 ± 12.8	63.5 ± 16.0
	HS	38.0 ± 3.4	36.9 ± 3.7	40.6 ± 5.6
	HL	17.5 ± 5.0	9.4 ± 2.2	15.9 ± 4.1
17:00–18:00	M	52.2 ± 15.2	58.5 ± 10.4	63.6 ± 14.4
	HS	32.0 ± 4.2	35.7 ± 3.0	46.4 ± 5.1
	HL	11.6 ± 3.9	8.3 ± 6.3	22.5 ± 1.9

**M* metabolic heat productioin, *Hs* amount of dry heat loss, *HL* amount of evaporative heat loss

Table 4 The rate of body heat storage and the rate of change in tympanic, mean skin, and mean body temperatures under three thermal conditions

Conditions	Time period	S^{*1}	$\dot{T}_{ty}^{*2}$	$\overline{T}_{sk}^{*3}$	$\overline{T}_{b}^{*4}$
Condition 1	9:00–10:00	− 19.3 ± 13.4	2.42 ± 0.31	0.02 ± 1.37	2.44 ± 1.08
	13:00–14:00	− 2.18 ± 16.2	3.2 ± 0.37	0.33 ± 1.06	2.63 ± 0.88
	17:00–18:00	8.62 ± 9.9	− 2.78 ± 0.31	1.18 ± 1.68	− 1.99 ± 2.30
Condition 2	9:00–10:00	2.22 ± 14.2	− 3.24 ± 0.26	0.6 ± 0.21	− 2.47 ± 0.21
	13:00–14:00	13.52 ± 18.0	− 2.2 ± 0.18	0.41 ± 1.15	− 1.68 ± 0.92
	17:00–18:00	14.45 ± 13.8	− 2.35 ± 0.18	− 0.13 ± 0.81	− 1.9 ± 0.60
Condition 3	9:00–10:00	17.33 ± 18.8	− 0.89 ± 0.30	1.35 ± 1.40	− 0.44 ± 0.10
	13:00–14:00	9.02 ± 13.9	0.31 ± 0.16	0.59 ± 176	0.37 ± 0.90
	17:00–18:00	− 5.34 ± 11.6	− 0.075 ± 0.55	− 0.62 ± 1.64	− 0.18 ± 1.68

S^{*1}, the rate of body heat storage (W/m2); $\dot{T}_{ty}^{*2}$, the rate of change in tympanic temperature (° C/h); $\overline{T}_{sk}^{*3}$, the rate of change in mean skin temperature (° C/h); $\overline{T}_{b}^{*4}$, the rate of mean body temperature (° C/h)

afternoon experimental periods to determine sex differences in physiological and psychological responses. As shown in Figs. 5 and 6, female subjects indicated thermal comfort in a wide range of TSVs, from neutral in the afternoon under conditions 2 and 3 to slightly cool in the evening under condition 3. Notably, female subjects perceived thermal comfort at lower $\overline{T}_{sk}$ in the afternoon and evening under condition 3. This result is consistent with that of Ugursal and Culp (2013), who reported that females consistently felt warmer and more uncomfortable than males under the same thermal conditions, and then

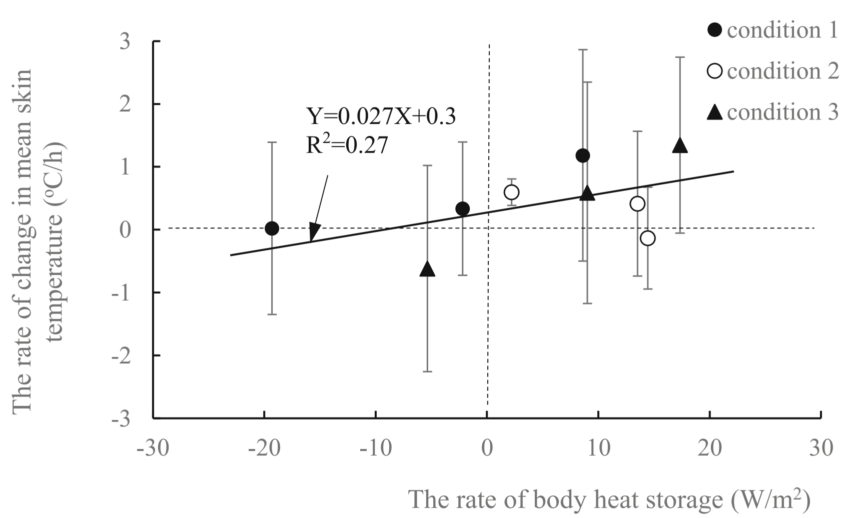

Fig. 4 Relationship between the rate of body heat storage and the rate of change in mean skin temperature. The rate of body heat storage calculated from body heat balance is promotionally correlated with the rate of change in mean skin temperature

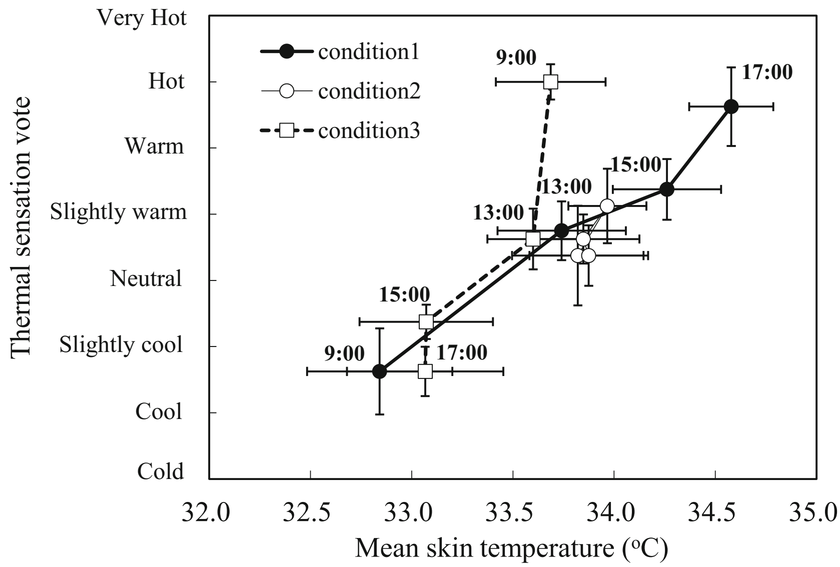

Fig. 5 Relationship between thermal sensation votes (TSV) and mean skin temperature (T_{sk}) under three thermal conditions. TSV changed from "cool" to "hot" when T_{sk} increased from 33.0 to 34.5 °C except for TSV in the morning under condition 3, when the ambient temperature was set at 30 °C

suggested that more heat needs to be carried to the skin surface in females in order to overcome the extra adipose layer's insulation. As shown in Fig. 5, female subjects reported feeling hot and uncomfortable at $\overline{T}_{sk} = 34$ °C, which has been described as a thermally neutral and comfortable temperature. Grivel and Candas (1991) conducted human experiments with 24 male and 24 female lightly clothed subjects seated at rest with no prescribed tasks for 3 h. Subjects were exposed to 25.1 °C for the first hour, and then allowed to set T_a to their preferred temperature for the following 2 h. The overall mean of individual average preferred temperatures was 26.6 ± 2.6 °C, with significant time-of-day (morning vs. afternoon) effects on preferred T_a and actual body temperature. Thus, the results of the present study agree with those of the previous study, with the female subjects in this study reporting being "slightly warm" in the afternoon under condition 2.

During these experiments, T_{ty} and $\overline{T}_{sk}$ were continuously monitored from 09:00 to 18:00 under three different thermal conditions. As shown in Fig. 2, T_{ty} increased continuously throughout the experimental period under condition 1, in which T_a increased from 26 °C to 30 °C. However, T_{ty} increased gradually from morning to evening under condition 2, in which T_a was consistently controlled at 28 °C, and remained almost unchanged under condition 3, in which T_a was decreased from 30 °C to 26 °C throughout the experimental period. This result indicates a persistent tendency in the female subjects to keep T_c unchanged during the daytime. To estimate the sex difference in body heat balance quantitatively, the results shown in Table 3 were compared with those of male subjects reported in the previous study (Kakitsuba and White 2013) because both results were obtained using the same experimental protocol. It was then confirmed that metabolic heat production and insensible heat loss were significantly higher ($p < 0.01$) in male subjects than in female subjects under nearly all conditions, whereas there were no sex differences in sensible heat loss except under a few experimental conditions. Using data indicated in Table 4, statistical analyses revealed that $\overline{T}_b$ and $\dot{T}_{ty}$ were not correlated with S in any period but proportionally correlated with $\overline{T}_{sk}$ as indicated in Fig. 4. These results indicate that the body-heat-balance equation cannot be used directly to predict diurnal changes in $\overline{T}_b$ in the case of female subjects. Therefore, the diurnal rhythm of body temperature in female subjects appeared to regulate changes in T_c more than changes in T_a during the daytime, except when there was a continuous increase in T_a. These sex differences support the findings of Morimoto et al. (1967) and Inoue et al. (2000), who demonstrated sex differences in temperature regulation during heat exposure, indicating the difficulty of applying the body-heat-balance equation to predict diurnal changes in T_c in women.

In conclusion, the present study first demonstrated effect of change in ambient temperature on core temperature of female subjects during the daytime and secondly demonstrated sex

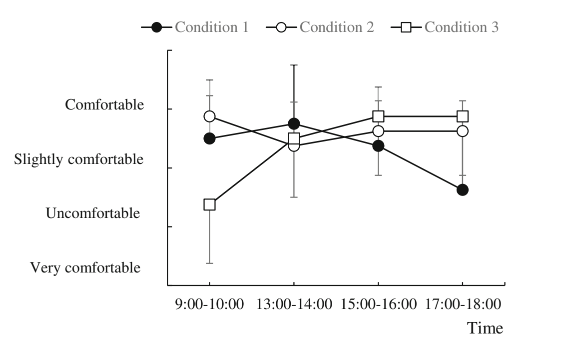

Fig. 6 Changes in thermal comfort vote (TCV) under the three thermal conditions. There were significant differences ($p < 0.05$) in TCV under conditions 1 and 3 in the evening and morning, respectively, as shown by changes in mean skin temperature

differences in physiological responses to identical heat stress conditions by changing T_a between the morning and evening by comparing with those of male subjects reported by a previous study (Kakitsuba and White 2013), and found that the rate of body heat storage estimated from the body-heat-balance equation may not be correlated with diurnal changes in T_c or $\overline{T}_b$ but $\overline{T}_{sk}$ in women under thermal conditions that do not induce shivering or extreme sweating. Thus, as compared with the male subjects, an endogenous function appeared to regulate changes in T_c more than changes in T_a during the daytime in female subjects.

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