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Circadian Fluctuation of Body Temperature in Different Thermal Conditions of the Distal Extremities by Clothing Type Worn during the Afternoon

Six healthy female volunteers twice undertook an experiment with different types of clothing leaving the arms and legs covered or uncovered at 24 ± 0.5°C and 50 ± 5% RH to study how different thermal stimulation to the distal extremities during the afternoon could modulate circadian parameters of body temperature rhythm. One type of clothing consisted of long-sleeved shirts and full-length trousers (Type I, 989 g, 0.991 clo); the other type consisted of half-sleeved shirts and knee-length trousers (Type II, 750 g, 0.747 clo). Subjects wore Type I or Type II clothing during the afternoon (14:00 h - 19:00 h), and Type I clothing during the evening (19:00 h - 22:30 h) and the night sleep (22:30 h - 06:00 h). Rectal temperature and skin temperatures at the arm and leg were measured continuously. Results were as follows: 1) The circadian amplitude of rectal temperature tended to be greater, and the acrophase was significantly earlier when wearing Type II rather than Type I clothing. 2) The circadian nadirs of skin temperatures of the arm and leg were significantly lower and the amplitudes were significantly greater with Type II clothing. In addition, the acrophase and bathyphase of the circadian rhythm of arm skin temperature were significantly earlier with Type II than Type I clothing. 3) The amplitude of rectal temperature was related closely with that of arm and leg skin temperature. These results suggest that a slightly cool thermal stress during the afternoon to the arms and legs exerted by wearing half-sleeved shirts and knee-length trousers induces a greater amplitude and a phase advance of the overt circadian rhythm of body temperature.

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All terrestrial creatures typically have circadian rhythms caused by the movement of the Earth. In humans, the core body temperature rhythm is one of the most well-established biological phenomenon (Aschoff & Heise, 1972; Hildebrandt, 1974; Minors & Waterhouse, 1981; Waterhouse *et al.*, 2005). The biological clocks controlling the core temperature are strongly entrained by bright light (Boresova *et al.*, 1991; Cajochen *et al.*, 1992; Czeisler *et al.*, 1986, 1989; Homma *et al.*, 1987; Park & Tokura, 1998a, 1999), and also influenced by ambient temperature (Candas *et al.*, 1979; Liu *et al.*, 1998; Robinson & Fuller, 1999; Ruoff & Rensing, 2004; Wakamura & Tokura, 2002). Humans can have some health problems if body rhythms are disordered due to certain internal or external components. It is desirable to live under the most suitable living environment for a healthy body rhythm.

Internal core temperature is controlled by nerve cells in the hypothalamus, there being separate centers for instigating heat loss mechanisms when core temperature starts to rise, and heat gain mechanisms when core temperature starts to fall. These thermoregulation responses are superimposed upon circadian changes that originated from the body clock (Moore, 1995; Refinetti & Menaker, 1991). Normally, it is widely recognized that changes in thermoregulatory effectors contribute to this temperature rhythm and include heat production, heat loss and whole-body heat loss rhythms (Minors & Waterhouse, 1981; Krauchi & Wirz-Justice, 1994; Robinson & Fuller, 1999). Many researchers (Aschoff & Heise, 1972; Hildebrandt, 1974; Smolender *et al*., 1993) have investigated that the circadian rhythm of core temperature is achieved mainly by mediations of heat loss via changes in cutaneous vascular tone of distal limbs.

Waterhouse *et al.* (2005) explained that the measured rhythm is a mixture of two components; an endogenous component that reflects the body clock and non-endogenous (exogenous) effects that are an impure reflection of the body clock. Moreover, Tokura and colleagues (Jeong & Tokura, 1990; Lee & Tokura, 1993; Park & Tokura, 1997, 1998b; Park, 2005) have demonstrated that in resting subjects, clothing acts as an external contributor to drive body temperature rhythm by controlling heat exchange between the body and the environment. In previous studies (Jeong & Tokura, 1990; Park & Tokura, 1997, 1998b), it was shown that the circadian amplitude was greater when wearing the clothing type uncovering the distal extremities rather than covering them in 24 - 28°C environmental conditions. This result was explained by the exposure of distal extremities to a moderate surrounding temperature might induce a higher daytime sympathetic nervous tone with less insulation due to the uncovered distal extremities and a greater relaxation of the activity during the subsequent night sleep.

There was limited attention to the influence of clothing on circadian phases of body temperature (Park & Tokura, 1998b), the study showed that the phase of daily rectal temperature was earlier by the exposure of the extremities to 24°C environmental condition from the early morning to the late evening (06:30 h to 22:30 h). In humans, the effects of a cool thermal stimulation on the thermoregulatory system can be greater in the early morning (heat gain mode) than in the late evening (heat loss mode), because of the circadian variation in the set-point of core body temperature (Waterhouse & Minors, 1995). Moreover, many investigators (Buresova *et al*., 1991; Czeisler *et al*., 1989; Honma *et al*., 1987; Minors *et al*., 1991) demonstrated that exposure to bright light (the most powerful synchronizer for human circadian rhythm) in the subjective morning may induce a phase advance while the application in the subjective evening, a phase delay of the core temperature rhythm. Furthermore, Hashimoto *et al.* (1997) disclosed that midday exposure (11:00 h to 17:00 h) to bright light advanced the onset and midphase of the plasma melatonin rhythm suggesting that bright light exposure during the daytime could deeply influence body temperature rhythm. Therefore, there is a possibility that the time of day of thermal stimulation to the extremities might influence the circadian phase of body temperature.

The present study is to confirm the effects of different thermal conditions of the distal extremities by clothing types worn during the afternoon upon the daily fluctuation and phase responses of body temperatures in understanding the relationships between core body temperature and skin temperatures at the arm and leg in terms of circadian rhythm.

MATERIALS AND METHODS

Subjects and Clothing

Six healthy young women aged between 19 and 27 years voluntarily participated in this study as subjects. They lived conventional lifestyles with regular sleep-wake daily cycles. The physical characteristics were shown in Table 1. All subjects were free from medication and none of them reported any sleep disorders. They were informed about the general purpose, procedure, possible risks, and the right to withdraw from the study at any point. Written informed consent was obtained prior to participation in the experiment. They were refrained from heavy physical exercise and drinking alcohol for at least 24 h before the start of each

Table 1. *Characteristics of Subjects*

Subjects	Age (years)	Height (cm)	Weight (kg)	BSA (m^2)	BMI
S1	24	158.7	52.0	1.52	20.65
S2	19	151.0	55.0	1.57	20.43
S3	27	158.0	51.0	1.50	17.04
S4	24	163.4	45.5	1.46	21.22
S5	24	155.0	45.0	1.45	18.73
S6	22	156.3	48.0	1.48	19.65
Mean	23	158.7	49.4	1.54	19.62
SEM	1	0.99	1.27	0.02	0.49

BSA (body surface area) was calculated as weight $(kg)^{0.425}$ × height $(cm)^{0.725}$ × 0.007184
BMI (body mass index) was calculated as weight (kg) / height $(m)^2$

Table 2. *Characteristics of Experimental Clothing*

	Clothing Type		Fiber Contents	Fabric Construction	Thickness (mm)
	Type I	Type II			
Outerwear	long-sleeved shirts, full-length trousers	half-sleeved shirts, knee-length trousers	50/50% cotton/polyester	single cross tuck stitch	1.62
Underwear	sleeveless shirts	sleeveless shirts	100% cotton	interlock stitch	0.72
	brassiere	brassiere	–	–	–
	briefs	briefs	100% cotton	plain stitch	0.38
Total Weight & Clo value	989 g 0.991 clo	750 g 0.747 clo	–	–	–

experiment. The subjects were tested twice with two different types of clothing. At the time of the study, all subjects who attended the experiment were at the luteal phase of their regular menstrual cycle to avoid the changes of temperature rhythm associated with ovulation (Bittel & Henane, 1974; Cunningham & Cabanac, 1971).

One of the types of clothing used in this study consisted of long-sleeved shirts and full-length trousers (Type I); the other consisted of half-sleeved shirts and knee-length trousers (Type II). This clothing was worn over sleeveless undershirts, a brassiere, and a pair of briefs. The total clo values estimated from clothing weight (Hanada *et al*., 1981) were 0.991 (989 g) for Type I and 0.747 (750 g) for Type II. The characteristics of the experimental clothing are listed in Table 2. The experiments with the two types of clothing were conducted in a randomized counterbalanced order.

Experimental Procedure

The entire study was carried out from 15th July to 30th August in Japan. Figure 1 shows the experimental protocol. The experiment was conducted in a climatic chamber controlled within an air temperature of 24 ± 0.5°C and a relative humidity of 50 ± 5% during the wakefulness and 28 ± 0.5°C during night sleep. Light intensity measured by an illuminator (Tokyo Photo Electric Co. Ltd., Japan) at eye level was 200 lux from 14:00 h to 19:00 h, 20 lux from 19:00 h to 22:30 h, and complete darkness from 22:30 h to 06:00 h. The chamber was also isolated from external sounds. Subjects were required to report to the laboratory at least 60 minutes before the start of measurements. On arrival, thermistor probes for measuring rectal and skin temperatures were equipped and the measurements were started at 14:00 h and continued until 06:00 h the next morning. Subjects dressed in either Type I or Type II clothing during the afternoon exposure (14:00 h - 19:00 h), and Type I clothing in the rest periods. They spent time in a sitting position reading books or listening to music during wake times, and a light evening meal was served at 18:00 h. The calories of each meal were almost the same in both experiments, and water was available at any time. However, the subjects were strictly not allowed to take a daytime

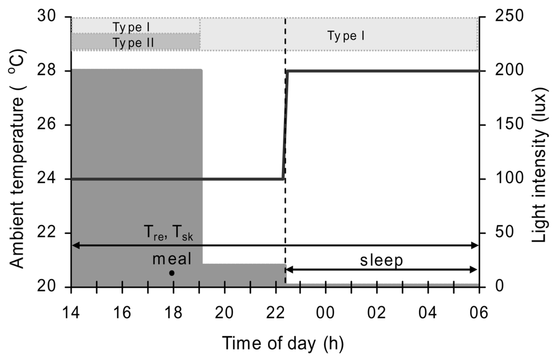

Figure 1. *Experimental Procedure*

nap. They slept from 22:30 h to 06:00 h without covering bedclothes to avoid possible effects on the thermophysiological responses.

Apparatus and Measurements

Rectal temperature was measured by a thermistor probe (RE type, Grant Instruments Ltd., UK; accuracy = ±0.05°C) inserted 12 cm beyond the anal sphincter, and skin temperatures from the lateral crural region and anterior antebrachial region were measured by epoxy-coated copper thermistor probes (EU type, Grant Instruments Ltd., UK; accuracy = ± 0.05°C). Rectal and skin temperatures were automatically logged every 10 minutes with a Squirrel Meter Logger (Grant Instruments Ltd., UK).

Data Analysis

The raw data of temperatures were inspected visually, and data segments that were affected by probe slippage were removed. Missing data were estimated by a liner interpolation procedure (Krauchi *et al.*, 1997). The plateau (maximum) and nadir (minimum) values of the circadian variations of rectal and skin temperatures and the time when those occurred were individually derived from the best fitting curves applied to each raw data. The fitted curve was obtained by the least-squares method with the cubic expression of the regression curve. The amplitude (Am), the one-half oscillation range of the temperature curve, was extracted by the following equation: $Am = (Pl - Na) / 2$, (Pl, plateau value; Na, nadir value). The acrophase and bathyphase are the peak time and through time of rhythm referenced to local midnight (00:00 h). The mean values of plateau, nadir, and amplitude between rectal temperature and distal skin temperatures at the arm and leg were compared with Friedman's ANOVA by ranks.

The differences of circadian parameters between the two clothing types were analyzed by Student's paired t-test. Wilcoxon matched-pairs signed-rank test was used to examine the relationship of the circadian amplitude between rectal temperature and distal skin temperatures. The values were generally expressed as mean ± standard error of mean (SEM). Exact p-values were given in the text, tables, and figures. The level of statistical significance was assessed at 5%, but the values where $0.05 < p < 0.10$ were reported as marginally significant.

RESULTS

The individual data and best fitting curves of circadian rhythms in rectal and distal skin temperatures for six subjects are shown in Figure 2 and Figure 3. Rectal temperature showed a clear circadian rhythm with higher values in daytime and lower values in nighttime while, the rhythm patterns of arm and leg skin temperatures described reversly from that of rectal temperature (i.e., lower in daytime and higher in nighttime).

Plateau, Nadir and Amplitude at Core and Distal Skin Sites

Figure 4 shows a comparison of the group means of plateau, nadir and amplitude for Type I and Type II clothing between the three temperatures, obtained by best fitting curves. The plateau value was significantly different between the body parts in both types of clothing (Friedman's ANOVA, $\chi^2 = 10.333$ and $p = 0.0017$ for Type I; $\chi^2 = 9.333$ and $p = 0.0055$ for Type II), the value was higher with the sequence being rectal temperature > arm skin temperature > leg skin temperature. The nadir value also showed the same tendency as the plateau value (Friedman's ANOVA, $\chi^2 = 12$ and $p = 0.00013$ in

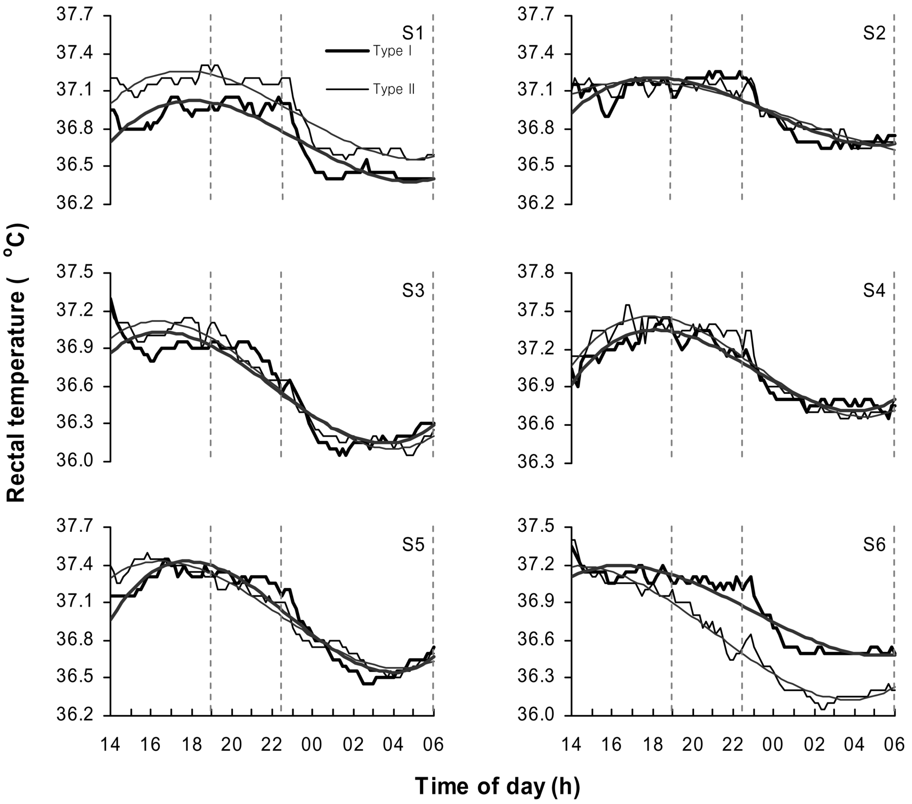

Figure 2. *Time Courses of Individual Rectal Temperature for the Two Clothing Types. Thick line, Type I; Thin line, Type II.*

Table 3. *Circadian Parameters of Body Temperature Rhythm by a Best Fitting Curve for the Two Clothing Types*

	Rectal Temperature		Arm Skin Temperature		Leg Skin Temperature	
	Type I	Type II	Type I	Type II	Type I	Type II
Plateau (°C)						
Mean	37.206	37.272	34.778	34.552	33.959	33.783
SEM	0.067	0.058	0.322	0.152	0.290	0.570
t-test	p = 0.081		p = 0.162		p = 0.331	
Nadir (°C)						
Mean	36.486	36.444	33.390	32.000	32.193	30.052
SEM	0.084	0.104	0.310	0.481	0.434	0.193
t-test	p = 0.288		p = 0.009		p = 0.001	
Amplitude(°C)						
Mean	0.360	0.415	0.694	1.276	0.883	1.866
SEM	0.029	0.039	0.232	0.266	0.163	0.223
t-test	p = 0.052		p = 0.013		p = 0.001	
Acrophase (h)						
Mean	17.481	16.221	3.012	2.372	2.817	2.420
SEM	0.450	0.528	0.768	0.731	0.355	0.463
t-test	p = 0.017		p = 0.028		p = 0.355	
Bathyphase (h)						
Mean	4.566	4.570	17.347	16.526	17.466	17.461
SEM	0.332	0.340	0.407	0.164	0.587	0.267
t-test	p = 0.496		p = 0.051		p = 0.491	

Note: 1. Acrophase and bathyphase were represented as a decimal time.

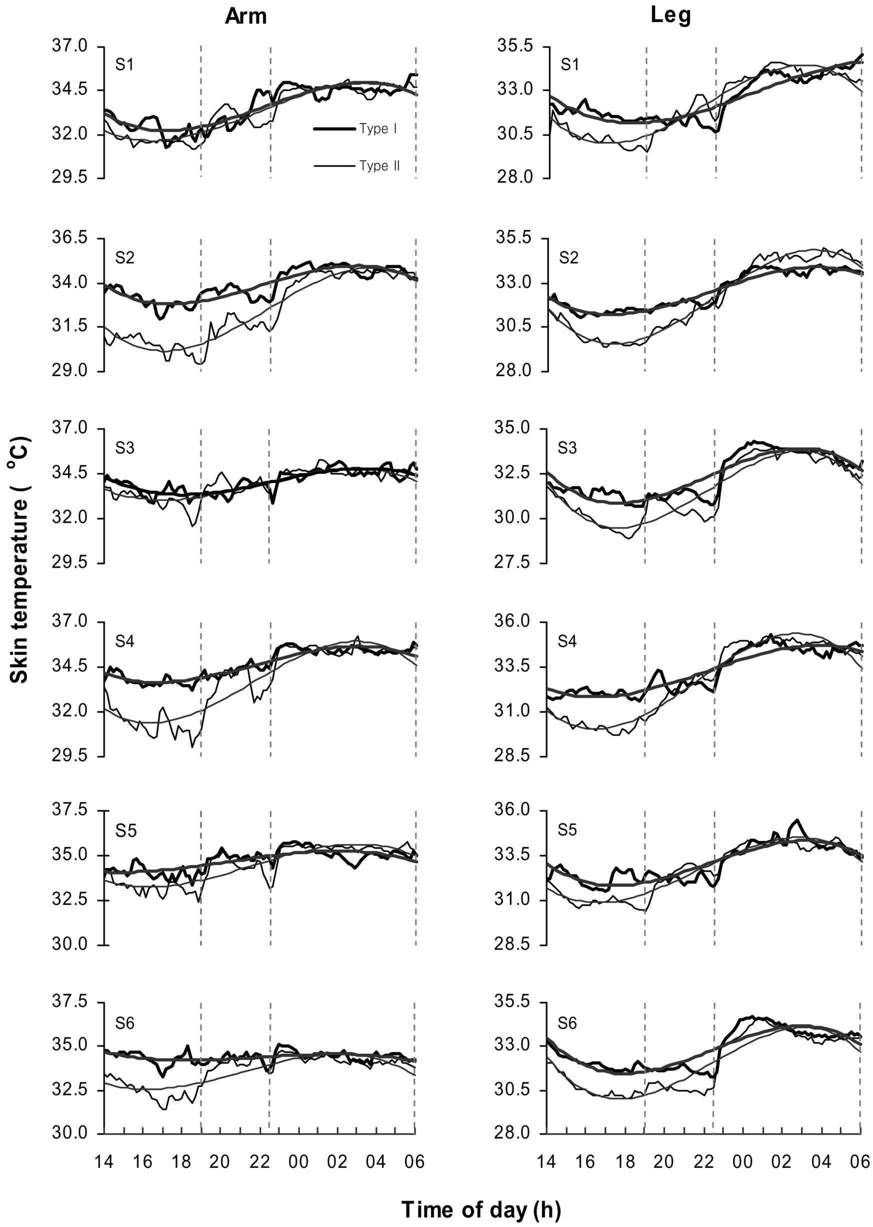

Figure 3. *Time Courses of Individual Skin Temperatures at the Arm and Leg for the Two Clothing Types. Thick line, Type I; Thin line, Type II.*

both of Type I and Type II). The circadian amplitude was significantly different between the three temperatures in the two clothing types (Friedman's ANOVA, $\chi^2 = 7$ and $p = 0.029$ for Type I; $\chi^2 = 10.333$ and $p = 0.0017$ for Type II), the value was greater with the sequence of leg skin temperature > arm skin temperature > rectal temperature.

Circadian Parameters for Clothing Types

Table 3 demonstrates the result of statistical analysis on each circadian parameter. When wearing Type II rather than Type I clothing, the plateau value of rectal temperature was higher in S1, S3, S4, and S5, and the nadir value was lower in S2, S3, S4, and S6,

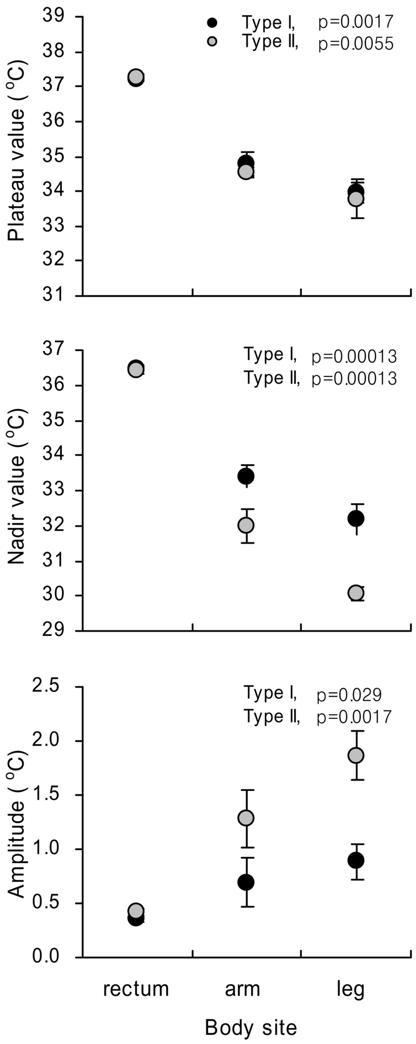

Figure 4. *A Comparison of the Plateau, Nadir and Amplitude Values between Rectal Temperature and Skin Temperatures at the Arm and Leg. Black Circle, Type I; Grey Circle, Type II.*

but the differences were not statistically significant (see Figure 2 and Table 3). In addition, the amplitude was marginally significantly different between the two clothing types (paired t-test, $p = 0.052$), showing greater values in five out of six subjects when wearing Type II clothing. In contrast, arm and leg skin temperatures showed significantly lower nadir values in Type II rather than Type I clothing (paired t-test, $p = 0.009$ for arm and 0.001 for leg). All subjects showed greater amplitudes of the skin temperatures in Type II clothing (paired t-test, $p = 0.013$ for arm and 0.001 for leg).

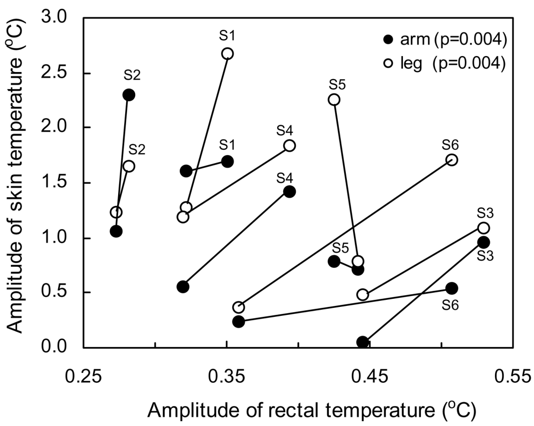

Figure 5. *The Relationship of the Circadian Amplitude between Rectal Temperature and Distal Skin Temperatures. Closed Circle, Arm; Open Circle, Leg.*

Furthermore, the circadian acrophase of rectal temperature was significantly advanced in Type II clothing (paired t-test, $p = 0.017$). Also, arm skin temperature showed earlier acrophase and bathyphase in Type II clothing (paired t-test, $p = 0.028$ for acrophase and 0.051 for bathyphase). However, leg skin temperature did not show any significant differences in circadian phase between the two clothing types.

Relation of Amplitude between Core and Distal Skin Temperatures

Figure 5 demonstrates that the relation of the circadian amplitude between rectal and distal skin temperatures. Statistical analysis indicated that the amplitude of rectal temperature was positively related to those of skin temperatures at the arm and leg except Subject 5 showed a smaller amplitude of rectal temperature in Type II clothing (Wilcoxon's signed-rank test, $p = 0.004$ in both cases).

DISCUSSION

The results obtained with rectal and skin temperatures in the current study were as revealed from the previous studies (Aschoff & Heise, 1972; Hildebrandt, 1974; Minors & Waterhouse, 1981; Park & Tokura, 1997, 1998a; 1998b). Namely, in resting subjects, rectal temperature was regulated with narrow limits around a value of 37°C (with an oscillation range of about 0.6 - 1.2°C) and was differently phased from distal skin temperatures (Figure 2 and Figure 3). As mentioned in the introduction, the diurnal changes in heat loss via changes in cutaneous vascular tone of distal limbs account mainly for the circadian variation of core body temperature (Aschoff & Heise, 1972; Hildebrandt, 1974; Smolender *et al.*, 1993). The above results would be explained by the heat loss from the skin temperature that is reduced during the daytime (heat gain mode) when core temperature is high or rising, and increased during the nighttime (heat loss mode) when core temperature is lower or falling (Krauchi & Wirz-Justice, 1994; Waterhouse *et al.*, 2001). Moreover, in the lower extremities, skin temperature was kept lower level and changed with a greater amplitude compared to the upper extremities (Figure 3 and Figure 4). These results were similar to the past investigations (Park & Tokura, 1997; Waterhouse *et al.*, 2005) that reported that the more distal from the trunk, the more the cutaneous temperature was lower and the circadian variation was great, while the circadian changes of trunk and forehead skin temperatures were closer to that of core temperature.

As seen in Figure 2, Figure 3, and Table 2, the amplitudes of rectal and skin temperatures were greater in Type II rather than Type I clothing in five out of six subjects for rectal temperature; in all subjects for arm and leg skin temperatures. Furthermore, the amplitude of rectal temperature was correlated positively with those of skin temperatures at the arm and leg (Figure 5). In the present study, direct exposure to the environmental condition of 24°C might cause a slightly cool thermal stress for the normally entrained subjects to summertime. This result suggests that when the stress was applied to the arms and legs by wearing half-sleeved shits and knee-length trousers, the cutaneous tone was greater in the uncovered extremities during the afternoon to reduce heat loss from the body. However, during the evening and night sleep the thermal stress was removed by wearing long sleeved shirts and full-length trousers and increasing the room temperature to 28°C. The nadir value of rectal temperature and the plateau values of arm and leg skin temperatures did not show significant differences by clothing types that the subjects wore in the afternoon. This result indicates that the marginally significantly greater circadian amplitude of core temperature in Type II clothing might be caused by the differences in the early afternoon due to direct exposure. The after-effect by the relaxation of sympathetic nervous system during the nighttime did not occur more strongly with Type II clothing, thus the nocturnal decrease of core temperature was not great. However, by the past study (Park & Tokura, 1998b), when this daytime thermal stress was applied from the early morning onwards, 12.4% of the circadian amplitude of core temperature was modulated by the after-effect. Furthermore, it was disclosed that the secretion of stress hormones, urinary catecholamines in the morning (from 06:30 h to 14:30 h) was greater by wearing clothing uncovering the distal extremities compared to covering them, but the secretion in the afternoon (from 14:30 h to 18:30 h) was not significantly different between the two conditions. Therefore, when considering the effects of thermal stimulation of the distal extremities upon the core body temperature rhythm, the applied time of day of the thermal stimuli is important (Park, 2005).

Type II clothing induced phase advances of the observed circadian rhythm in core and arm skin temperatures as seen in Figure 2, Figure 3, and Table 2. Robinson and Fuller (1999) found that the circadian rhythm of heat loss was phase-advanced at an air temperature of 17°C than at 27°C when studied with the squirrel monkey. Wakamura and Tokura (2002) disclosed that the circadian phase of rectal temperature was advanced in the condition of a gradual decrease of ambient temperature (*T*a) in the evening and a gradual increase in the morning (*T*a decreased from 25°C to 22°C over 4 hours from 18:00 h to 22:00 h, was then kept 22°C for 6 hours and increased to 25°C over 4 hours from 04:00 h to 08:00 h) compared to the reversed condition (*T*a was changed from 25°C through 28°C to 25°C with identical time schedule). These observations suggest that the circadian phase of thermoregulatory system might be influenced by the environmental thermal conditions. The phase advances observed in Type II clothing might be caused by a cooler thermal stress during the afternoon. However, even though the acrophase of rectal temperature was advanced with Type II clothing, the bathyphase was not significantly different between the two clothing types. While the acrophase and bathyphase of the overt circadian rhythm in arm skin temperature was affected by the type of clothing, the effects were not observed in leg skin temperature in both phase values. These results represent a simple masking effect (an exogenous effect) of clothing upon the circadian oscillator of body temperature. This study was conducted with a 16 hour experimental schedule (shorter than 24 hours) even though the acrophase and bathyphase were included in the experimental period and the shorter schedule might have affected the accuracy of the estimation of the circadian phase parameters.

CONCLUSIONS

A slightly cool thermal stress to the arms and legs during the afternoon by wearing clothing which uncovered the distal extremities enhanced the circadian amplitudes of rectal temperature and cutaneous temperatures at the arm and leg, and induced phase advances of the overt circadian rhythm in rectal and arm skin temperatures. The circadian amplitude of rectal temperature and those of distal skin temperatures were positively closely linked each other. These results confirm that the circadian rhythm of core temperature is achieved by mediations of heat loss from distal limbs. The effects of cool thermal exposure of the distal extremities by the type of clothing worn during the daytime upon the circadian rhythm of body temperature might differ depending on the time of day of the application. However, this study was performed with a short experimental schedule on a small number of subjects entrained to natural summertime, further studies are needed to draw definitive conclusions on the effects of clothing type upon the circadian phase of body temperature by conducting the experiment over a 24 hour or longer schedule on a larger number of subjects over different seasons.

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