Annual Periodicity of Thermal Responses in Exercising Human

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Abstract

In order to investigate the annual periodicity in thermal responses during exercise, adult healthy men repeated moderate muscular work by a bicycle ergometer in a climatic chamber of an ambient temperature of 30℃ (rh,45%) in winter, spring, summer and fall. In summer, sweat rate (SR) immediately increased as soon as the exercise started, whereas in winter in a few minutes. The average SR both at rest and during exercise was significantly different ($p<0.01$) between winter and summer season. The transient reduction of mean skin temperature ($\bar{T}_{sk}$) was observed at the beginning of the exercise in winter. $\bar{T}_{sk}$ decreased in proportion to increasing of SR in each season. Significantly negative correlations ($p<0.01$) were found between SR and the rate of change of $\bar{T}_{sk}$ during in each season. The regression equation was significantly different ($p<0.01$) between winter and summer. It is suggested that the present results may reflect adapted changes in the thermoregulatory mechanisms to temperature acclimation.

Key Words: Bicycle exercise, warm and cold seasons, whole body sweat rate, thermoregulation

Seasonal variation of physiological responses to exercise in terms of energy expenditure, heart rate, forearm blood flow, maximal aerobic power and body temperatures has been reported by many investigators[1)2)5)6)11)19)]. Araki *et al.* (1981)[1)] present sweat rate during exercise measured in summer and winter, and Yasuda & Miyamura (1983)[19)] notify the same measurement in four different seasons. Above papers do not sufficiently provide the mechanism and the role associated with seasonal acclimatization. The present research is concerned with the seasonal variation of thermoregulatory responses to exercise to assess a role of skin sweating and body temperatures, and the relationship between the both roles and seasonal acclimatizations.

Methods

Subjects: Subjects, living in Kumamoto city, were three untrained and nonheat-acclimated men. The subjects' ages and physical characteristics were shown in Table 1.

Table 1 Physical characteristics of the subjects

Subj.	Age (yr)	Ht (cm)	Wt (kg)	B.S.A. (m^2)
A	28	165	63	1.70
B	30	185	86	2.11
C	28	166	68	1.77

Protocol: The subjects arrived at 8:30 am in our laboratory without breakfast. They maintained at least 30 min resting level on a chair at an appropriate room temperature in each season: in winter, 10℃, in spring, 15℃, in summer, 29℃, and in fall, 18℃. The experiments were conducted between 9:00 am and 11:00 am. Experiments on any individual were performed at the same of day to avoid variability attributable to the circadian rhythm of body temperature[16]. After maintained resting condition (control exp.) for 20 min on a bicycle ergometer, the subjects performed bicycle exercise for 20 min. After the exercise, they stayed on the bicycle ergometer over 10 min. All experiments were carried out in a climatic chamber in which the environmental temperature (T_a) was controlled at 30℃, and relative humidity (rh) maintained a constant of 45 %. In order to obtain effective skin sweating, an electric fan, placed 1.5 m behind the subjects, was always used. The experiments were perfomed repeatedly the climatic chamber in February, from late April to early May, August and October. The exercise was perfomed on the bicycle ergometer placed on a Potter bed scale, and the work intensity was about 40 % of maximal aerobic power ($\dot{V}o_{2\cdot max}$) in each subject. The pedal frequency was kept at 30 rpm using a metronome.

Measurement and Estimation: Skin sweating and rectal (T_{re}) and skin temperatures were simultaneously measured. Sweating loss was monitored continuously by a bed scale (J. A. Potter, Model 33B, sensitivity 1 g) with automatic electronic weight change indicator. The best curve was drown throughout the weight record of each experiment and the rate of whole body weight loss was then calculated over 1-min interval by differentation of the curve[18]. The balance was calibrated prior to each experiment. The temperatures of seven skin surface locations and T_{re} at depth of 10-12 cm from the anus were recorded spontaneously every minute by copper-constantan thermocouple recording system (Ohkura Elect. Co., AM-300) throughout experimental period. Mean skin temperature ($\bar{T}_{sk}$) was calculated from Hardy-DuBois equation.[13,14]

Changing rate (ΔSR) against annual value of total sweat loss (TSL) during the exercise in four seasons was calculated the following equation.[17]

$$\Delta SR = (SR_1 - SR_2) / SR_2 \times 100\ (\%)$$

where SR_1 is TSL during the exercise in each season; SR_2 is annual mean value of TSL.

Statistical Analysis: Values represent mean $\pm$ SD. The statistically significant difference between mean values and of the regression equation were assessed by paired Student's *t*-test and co-variance analysis, respectively. The level of significance was set up $p < 0.05$.

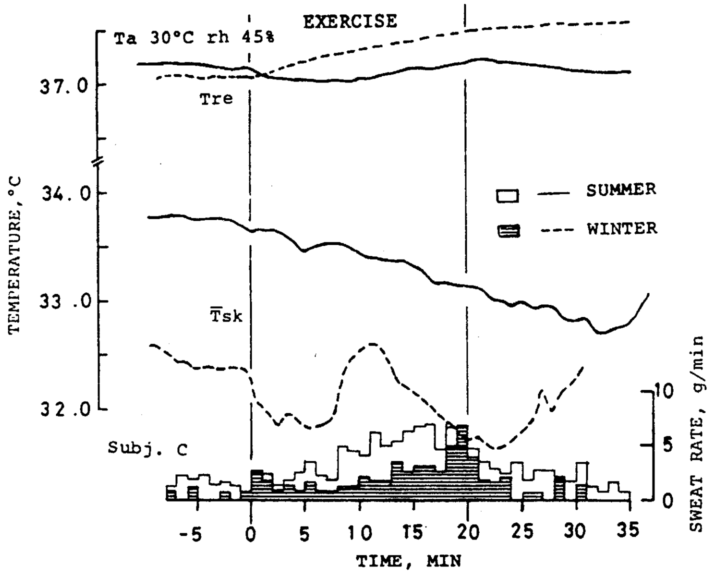

Figure 1. The comparison of time course in sweat rate, rectal temperature (T_{re}) and mean skin temperature ($\bar{T}_{sk}$) in summer (solid lines) with that in winter (dashed lines) closed circle during rest, exercise and recovery. The sweat rate is shown by open column in summer and shaded column in winter. Subject, *C*. Environmental condition, an ambient temperature (T_a) 30 ℃ and a relative humidity (rh) 45 % are identical in each season.

Results

Figure 1 shows time course of sweat rate (SR), T_{re} and $\bar{T}_{sk}$ during rest, exercise and recovery in summer and winter. In summer, as soon as the subjects started to the exercise, the onset of sweat secretion was observed for all experiments. But in winter it did not increase noticeably until a few minutes. The mean SR during the exercise was significantly higher in summer than that in winter (Table 2). Average values of TSL were 104, 139,

Table 2 Mean sweat rate during rest, exercise and recovery in winter, spring, summer and fall.

Subject	Season	Mean Sweat Rate (g/min) Rest	Exercise	Recovery
A	Winter	1.1±1.1	4.2±2.4	2.1±1.8
	Spring	1.2±0.5	4.6±2.8	2.9±2.3
	Summer	2.0±1.3**	6.6±4.3***	3.1±2.9
	Fall	1.8±2.3	4.6±2.0	—
B	Winter	1.3±0.8	3.0±1.4	—
	Spring	1.2±0.7	3.9±1.8*	3.2±2.3
	Summer	2.2±1.4**	4.3±1.3***	3.3±1.8
	Fall	0.8±1.0	4.3±2.0**	2.7±1.4
C	Winter	1.1±0.5	2.3±1.5	1.7±1.1
	Spring	0.8±0.6	4.2±2.7**	2.4±1.2
	Summer	2.0±1.5**	4.3±1.8***	2.4±1.0
	Fall	1.1±1.0	4.0±2.0***	2.5±1.5

Values are indicated by mean±SD.
Significantly different from Winter, *$p<0.05$, **$p<0.01$, ***$p<0.001$.

Table 3 Seasonal variation of total sweat loss (TSL) and changing rate of the mean TSL (ΔSR)

Subject		A.	B.	C.	Mean
TSL (g/m²·h)	Winter	148	86	80	104
	Sprjng	162	111	144	139
	Summer	234	124	144	167
	Fall	164	124	139	142
	Mean	177	111	126	138
ΔSR (%)	Winter	−16.3	−22.5	−36.5	−25.1
	Spring	− 8.4	±0	+14.2	+ 1.9
	Summer	+32.2	+11.7	+14.2	+19.3
	Fall	− 7.3	+11.7	+10.3	+ 4.9
annual	range (%)	48.5	34.2	50.5	44.4

167 and 142 g/m^2·h in winter, spring, summer and fall, respectively. There was the changing rate against annual mean value of the TSL of -25.1 % in winter and of +19.3 % in summer, and there was the annual range of 44 % (Table 3).

T_{re} at rest was not influenced by seasonal factors. In winter T_{re} during exercise was observed a marked elevation in comparison with resting level. After the exercise (recovery) the T_{re} did not return to resting level within 15 min in winter, but the T_{re} did not increase in summer. On the other hand, $\bar{T}_{sk}$ in summer was about 1℃ over its level of winter. Furthemore, $\bar{T}_{sk}$ at rest was higher in summer (33.7 ± 0.5℃, mean ± SD, n=3) than in winter (33.0 ± 0.3℃, n=3) under the same thermal conditions (T_a30℃, rh, 45 %). A transient reduction in $\bar{T}_{sk}$ at an initial stage of the exercise was observed in winter, but in summer the $\bar{T}_{sk}$ decreased gradually after the exercise started. There was the negative correlation between individual SR and change in $\bar{T}_{sk}$ against initial value ($\Delta\bar{T}_{sk}$). Analysis of co-variance revealed a significant difference between the regression equations in summer and winter ($p<0.01$) (Table 4). Although there was a significant difference among the SRs in four seasons ($p<0.01$), the reduction of $\bar{T}_{sk}$ was independent of seasons. The fall in $\bar{T}_{sk}$ was 1.0±0.1℃ (mean±SD,n=12) throughout exercising period.

Table 4 Comparison of regression lines, SR vs. $\Delta\bar{T}_{sk}$ in summer and winter

					Deviations from Regression		
	df	Σx^2	Σxy	Σy^2	*df*	*SS*	*MS*
With in Summer	59	11.5	−47.1	417.7	58	224.8	3.87
Winter	59	8.0	−23.6	217.7	58	148.1	2.55
					116	327.9	3.21
Pooled, W	118	19.5	−70.7	635.4	117	379.1	3.24
Difference between slopes					1	6.20	6.20
Between, B	1	0.4	−6.8	104.5			
W + B	119	19.9	−77.5	739.9	118	436.5	
Between adjusted means					1	57.5	57.5

Comparison of slopes: F=6.20/ 3.21=1.93 (df=1,116) *NS*

Comparison of elevations: F=57.5/ 3.24=17.7 (df=1,117)**

There were seasonal changes in ΔSR and $\bar{T}_{sk}$ at the end of exercise. The average SRs during exercise in various seasons were dependent on the absolute level of $\bar{T}_{sk}$. There was significant correlation (r=0.73, $p<0.01$) between ΔSR and the level of $\bar{T}_{sk}$ rather than that between TSL and one (r=0.53,$p>0.05$) (Fig.2).

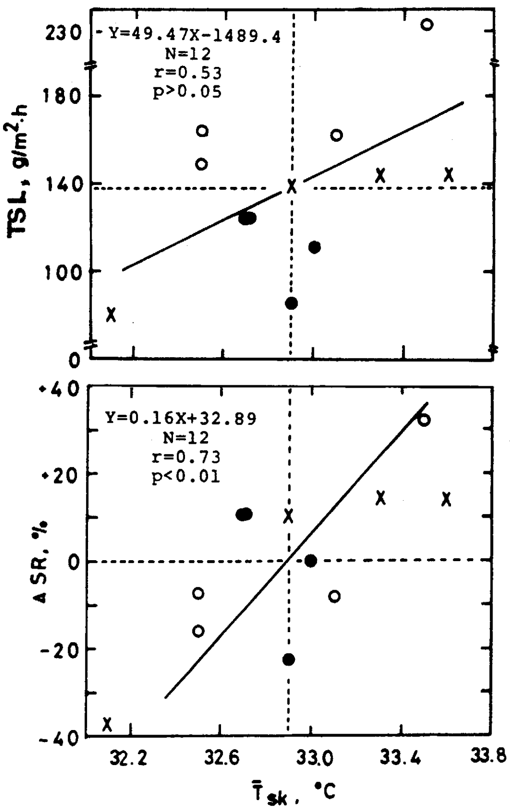

Figure 2. Correlation between TSL and $\bar{T}_{sk}$ (upper panel) and ΔSR and $\bar{T}_{sk}$ (lower panel). o=Subj. *A*, x=B, ● =*C*. Broken lines indicate average value.

Discussion

The present results demonstrate that the onset of sweat secretion in summer is remarkably earlier than in winter. Although there is a significant difference in sweating pattern in various seasons, the reduction of skin temperature was independent of seasons. It is approximately 1 ℃. Thus, the onset of skin sweating is shown to occur earlier and sweating becomes more profuse in the warm season than in the cold season, when subjects are exercising at the same environmental conditions, as pointed out by Kuno (1956)[4] and Nadel *et al.* (1971)[7]. Fruthermore, we previously demonstrates that when subjects do exercise at the identical work intensity at two different ambient temperatures of 30 and 40℃, the sweating rate in the exercise is significantly higher at 40 than 30℃, but the decreasing value in skin temperature is almost equal in the both environments[12].

In our experiment, an electric fan was placed 1.5 m behind the subject to obtain the effective skin sweating. Nadel & Stolwijk (1973)[8] report that skin sweating is enhanced significantly in any given environment with a wind velocity of 2.2 m/sec, compared to 0.1 m/sec. We may indicate that the reduction of skin temperature is closely related to both non-thermal and thermal factors, such as the evaporative heat loss.[14)15]

Nielsen (1970)[9] specifies that the rate of heat production due to muscular exercise is closely related to work load rather than to an ambient temperature. In this case, the increase in core temperature is significantly correlated to that in the heat production. Moreover, Saltin & Hermansen (1966)[10] observe that the increase in core temperature is proportional, not to the absolute value of metabolic rate, but to the relative work load, *i.e.*, to the percentage of the individual's $\dot{V}o_{2max}$. Masuda (1967)[5] reports that the heat production during exercise of relative metabolic rate (RMR) of 5 to 8 is not effected by the seasonal factor. Matsui *et al.* (1978)[6] investigate $\dot{V}o_{2max}$ in four seasons, finding no significant relationship of $\dot{V}o_{2max}$ with season. In our experiment, the work load was 40 % of individual's $\dot{V}o_{2max}$ throughout the year. Thus, assuming that metabolic heat production exercising man under constant work intensity is at least the same level in four seasons, the elevation of the core temperature in the warm season may be considered to be same as that in the cold season.

Shapiro *et al.* (1981)[11] report functional difference of the results in acclimatization to heat (T_a40℃ & rh, 30 %) in winter and summer, and that the T_{re} in winter was consistently and significantly (0.15 - 0.35℃) higher than that found in summer experiments.

On the other hand, sweating reaction in summer was characterized by a relatively smaller salt loss despite of a greater water loss, while the rise in core temperature was less in summer than in winter.[3] Araki *et al.*, (1981)[1] report that the sweat rate is remarkably higher in summer than in winter, when physically untrained and trained women, aged 19 - 22, performe a bicycle ergometer at three different work intensities for 2 h in summer and winter in a T_a30℃ and rh of 60 %. In addition, Yasuda & Miyamura (1983)[19] presente that, forearm blood flow during exercise is greater in summer than in winter, and that the difference between in summer and winter at any given core temperature during exercise is statistically significant.

In summary, the average SR and TSL during exercise are significantly higher in summer than winter (Table 2 & 3). The T_{re} also markedly increases in winter in comparison with in summer, and $\bar{T}_{sk}$ decreases in proportion to the increase of SR in each season (Fig.1). Negative correlations are found between SR and $\Delta\ \bar{T}_{sk}$ during exercise in each season. The regression equation is significantly different between in winter and summer (Table 4). These findings may indicate that there is the functional change in the thermoregulatory mechanisms to temperature acclimatization in the exercising human.

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