Effect of prewarming in the cold season on thermoregulatory responses during exercise

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Abstract

Objective—To assess whether thermoregulation in the cold season can be affected by prewarming before exercise.

Methods—Four healthy non-athletic unacclimatised males were exercised to the same degree in summer and winter on a bicycle ergometer without prewarming (experiment 1) and after prewarming by sitting for 30 min in a room at 30°C (experiment 2). During exercise, sweat production and rectal and skin temperatures were measured continuously.

Results—There was seasonal variation in sweating capacity and sensitivity and in heat storage during exercise without prewarming (experiment 1). After the subjects were warmed before exercise, there was no such seasonal variation in their sweat rates during exercise at 30°C and 40°C (experiment 2). In both cases, the sweat rate and skin temperature were dependent on the environmental temperature, and the sweat rate and core temperature were dependent on the workload. In the cold season, sweating sensitivity and evaporative cooling response could be enhanced by thermal stimulation. There was no seasonal difference in the relation between evaporative heat loss and metabolic rate in the two thermal conditions. These values did not differ significantly between winter after prewarming and summer ($P > 0.05$), neither did heat storage and metabolic heat production at various workloads ($P > 0.05$).

Conclusions—There is adaptation of the thermoregulatory mechanisms during temperature acclimatisation. Body warming enhances not only the heat dissipating activity of the thermoregulatory centre but also the induction of peripheral sweat gland activity. Seasonal change of sweat rate in exercising men can be eliminated through a different type of acclimatisation by prewarming in the cold season.

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Key terms: loss of seasonal change; submaximal exercise; warm up; thermoregulation; thermal balance; metabolic rate; evaporative heat loss.

Several reports have been published on seasonal variation of physiological responses to exercise. These responses include metabolic heat production,¹ heart rate,¹ forearm blood flow,² maximum aerobic work capacity,³ and changes in body temperature.^{2,4} Shapiro and his coworkers⁵ observed the differences between acclimatisation to heat (40°C, relative

humidity 30%) in winter and in summer. The rectal temperature in winter was consistently higher (0.15–0.35°C) than in the summer experiments. The sweating reaction in summer was characterised by a relatively smaller salt loss despite a greater water loss, while the rise in core temperature was less in summer than in winter.⁶ Araki *et al*⁴ have reported on physically inactive and active women, aged 19–22 years, exercising on a bicycle ergometer at three different work intensities for two hours during summer (July–August) and winter (January–February) at an ambient temperature of 30°C and a relative humidity of 60%. In both groups, the sweat rates were markedly higher in summer than in winter.

On the other hand, heat acclimatisation studies have established the beneficial effects of acclimatisation on thermal responses to dry or wet heat.^{7–10} After heat acclimatisation, sweat rate, sweating efficiency, and sweating sensitivity increased and body core temperature and heart rate decreased compared to the non-acclimatised state. Moreover, during heating of the body in human subjects, skin blood flow in a limb outside the heated area increases, while at the same time the muscle blood flow may decrease.¹¹ This must be taken into account when thermoregulatory changes in cutaneous blood flow are assessed by plethysmography of muscular parts of limbs (for example the forearm) or when measuring total blood flow of the extremities.^{12–14} Moreover, Ogawa *et al* found that local sweat rate of the warmed areas increased with repeated heating of a localised area of the skin.¹⁵ Clearly it is important to examine human thermoregulatory responses during exercise, especially heat balance regulation. The previous reports, however, do not adequately account for seasonal and temperature acclimatisation and its mechanisms.

Key to abbreviations

VO₂ max = maximum oxygen uptake
RH = relative humidity
T_a = ambient temperature
T_{re} = rectal temperature
T_s = mean skin temperature
T_b = mean body temperature
m_{sw} = sweat rate
TSR = total sweat rate
ΔTSR = change in total sweat rate
TSR_{es} = TSR during exercise in each season
TSR_{an} = annual mean value of TSR
M = metabolic rate
W = external work
E = evaporative heat loss
R + C = radiative and convective heat loss
S = change in heat storage
BSA = body surface area

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The purpose of our study was therefore to assess whether sweating capacity and sensitivity in the cold season can be enhanced by thermal stimulation. This study concerns seasonal variation in thermoregulatory responses to exercise and aims to assess the role of thermal balance, and its relation to seasonal acclimatisation. We also tried a quantitative approach to the thermal regulatory mechanisms involved in thermal balance during submaximal exercise under heat stress. Preliminary results were published earlier.¹⁶

Methods

SUBJECTS AND GENERAL METHODS

The subjects were four healthy males from Kumamoto, Japan, which is located at 33°N. Table 1 shows characteristics of the subjects. All were inactive males who had not participated in any regular physical conditioning for several years at least preceding the experiment, and had not been heat acclimatised. The subjects undressed to their underwear in a climatic chamber. The body weights shown in table 1 were measured in the winter experiment, and the annual range of weight was from 800 to 1200 g in each subject. Before the main experiments, the subjects' maximum oxygen uptake ($\dot{V}O_2$ max) was determined by incremental loading and the Douglas bag technique.¹⁸ Bicycle ergometer tests were carried out by the incremental loading technique with a Monark-type ergometer. The pedalling rate was kept constant at 50 rpm and timed with a metronome. After 2 min of pedalling with a constant load ($600\text{--}660\text{ kpm}\cdot\text{min}^{-1} = 100\text{--}110\text{ watts}$), the workload was increased by $150\text{ kpm}\cdot\text{min}^{-1} = 25\text{ watts}$ every minute up to exhaustion.

Two series of experiments were conducted in a climatic chamber with controlled temperatures at 30 and 40°C (ambient temperature, T_a) and a relative humidity (RH) of 45%. Wind velocity in the climatic chamber was controlled with $0.8\text{ m}\cdot\text{s}^{-1}$. The subjects performed bicycle exercise at various work intensities (see table 1). The pedal frequency was kept at 50 rpm using a metronome. Measurements of whole body sweating, rectal temperature (T_{re}), skin temperature (T_{sk}), and oxygen uptake ($\dot{V}O_2$) were carried out throughout the experimental period.

The experiments on each individual were conducted at the same time of day to avoid variability attributable to the circadian rhythm of body temperature.¹⁹ All experiments were carried out between 10:00 am and 1:00 pm, with the order randomised. No heavy muscular activities were performed for 24 h before any

test. On the experimental day, the subjects conducted cycle exercise without taking breakfast.

Seasonal averages of mean outdoor temperature during the following experimental period in Kumamoto City were 2.9°C in winter (February); 14.8°C in spring (April); 27.6°C in summer (August), and 17.2°C in autumn (October).

EXPERIMENT 1: SEASONAL VARIATION OF THERMOREGULATORY RESPONSES DURING EXERCISE

The subjects arrived at the laboratory between 8:00 and 8:30 am. They rested for at least 30 min on a chair at the normal (or natural) room temperature for each season: in winter, 10°C; in spring, 15°C; in summer, 28°C; in autumn 18°C (see fig 1). During this session, the subjects' clothes were as follows: in summer: underwear, shorts, and a cotton shirt with half length sleeves; in winter: underwear, shorts, a cotton shirt with long sleeves, a V-neck sweater, trousers, socks, and a jacket; in spring and autumn: underwear, a cotton shirt with half length sleeves, trousers, and socks. After resting for 10 min on a bicycle ergometer, the subjects exercised for 20 min, and afterwards stayed on the bicycle ergometer for more than 10 min. All experiments were carried out in a climatic chamber where the T_a was maintained at 30°C, and RH at a constant 45%. The experiments were performed repeatedly in February, April, August, and October. The bicycle ergometer was placed on a Potter bed scale (automatic weight loss indicator), and the workload was about 40% of $\dot{V}O_2$ max in each subject.

EXPERIMENT 2: EFFECT OF PREWARMING IN WINTER ON THERMOREGULATORY RESPONSES TO SUBMAXIMAL EXERCISE

Experiment 2 consisted of 48 trials using three males, and this experiment was carried out from January to early February and in August in the season following that in which experiment 1 was conducted. The same subjects as in experiment 1 exercised moderately for 20 min after warming (sitting on a chair for 30 min in a room at 30°C). The experimental technique and procedures and the environmental conditions were the same as for experiment 1 (see fig 1B).

After the prewarming, the subjects performed exercise at the same work intensity as in experiment 1. Exercise testing was carried out at two different workloads, 60% and 80% of $\dot{V}O_2$ max, at T_a of 30°C, and at the same workloads at a T_a of 40°C (see fig 1C). In August, the same experiments were conducted

Table 1 Physical characteristics of the subjects and their submaximal work loads

Subject	Age (years)	Height (cm)	Weight (kg)	BSA (m ²)	$\dot{V}O_2$ max (ml·kg ⁻¹ ·min ⁻¹)	% of $\dot{V}O_2$ max (watts)		
						40%	60%	80%
A	28	165	63	1.70	43.7	60	90	125
B	30	185	86	2.11	31.6	60	—	—
C	28	166	68	1.77	38.5	60	90	125
D	22	167	55	1.62	51.4	80	110	140

Body surface area (BAS) was estimated by Takahira's equation.¹⁷ Maximum oxygen uptake ($\dot{V}O_2$ max) was determined by a bicycle ergometer and modified technique of Miyamura and Honda.¹⁸

heat loss, $R + C$ = radiative and convective heat loss, and S = change in heat storage of the body. M was estimated by the equation, $M = \dot{V}O_2 \pm 5.0 \pm 60/BSA$, where $\dot{V}O_2$ = oxygen consumption in litres·min⁻¹, 5.0 (or 4.8) = caloric value produced by consumption of 1.0 litre of oxygen during exercise (or at rest) in kcal, and BSA = body surface area. E was estimated from the assumption that 0.58 kcal of heat is lost for 1.0 g of water evaporated from the skin surface. W was calculated by Nielsen's equation.²⁶ Heat exchange by radiation (R) and convection (C) were calculated using the Fanger's²⁷ and Nishi and Gagge's²⁸ formulas, respectively. For estimating S , we used Stolwijk and Hardy's equation.²⁵ In the present study the values of thermal balance were converted in $W \cdot m^{-2}$ of the body surface.

STATISTICAL ANALYSIS

The values are given as mean (SEM). Statistically significant differences between mean values were assessed by paired Student's t test, one way (season and individual) or three way analysis of variance ANOVA (season $\times T_a \times$ workload). A probability level of 0.05 or less was accepted as a significant difference.

Results

EXPERIMENT 1: SEASONAL VARIATION OF THERMOREGULATORY RESPONSES DURING EXERCISE

In summer, as soon as the subjects started to exercise, onset of sweat secretion was observed in all experiments. In winter sweat secretion did not occur until after a few minutes. The mean $\dot{m}_{sw}$ during exercise was higher in summer than in winter, at 5.2 (0.6) *v* 3.2 (0.4) g·min⁻¹ ($P < 0.01$). Average values of TSR were 108 (15.7), 139 (14.9), 178 (26.2), and 142 (11.7) g·m⁻²·h⁻¹ in winter, spring, summer, and autumn, respectively ($P < 0.01$, one way ANOVA). There were Δ TSR values of -25.8 (4.3)% in winter and +21.5 (5.0)% in summer ($P < 0.01$), with an annual range of 47.7 (4.7)%. Increased T_{re} caused by exercise was significantly higher in winter than in summer. In winter, S was positive but in other seasons it was negative. There were significant differences between summer and winter values of S : -11.1 (4.5) *v* 17.5 (8.6) $W \cdot m^{-2}$, respectively.

EXPERIMENT 2: EFFECT OF PREWARMING IN WINTER ON THERMOREGULATORY RESPONSES TO SUBMAXIMAL EXERCISE

The results in experiment 1 and of light exercise in experiment 2 are summarised in

table 2. When the same thermal stimulus was given by having a room temperature of 30°C for 30 min (prewarming) before exercise in winter, there was no seasonal variation in the sweating response to the exercise. There were no significant differences between mean $\dot{m}_{sw}$ and TSR and Δ TSR in summer and winter following prewarming ($P > 0.05$). The annual range of Δ TSR change in experiment 1 (based on data in winter) and in experiment 2 (based on data in winter after prewarming) was 47.7 (4.7)% and 25.5 (5.8)%, respectively ($P < 0.01$). The annual range of Δ TSR in experiment 2 decreased by 46% in comparison with experiment 1.

Figure 2 shows the changes of T_{re} and S caused by exercise in various seasons. There was no significant difference in T_{re} before exercise in each season. T_{re} postexercise in winter after prewarming was not significantly different from in summer. S in summer was not significantly different from S in winter after prewarming: -12.5 (4.5) *v* -5.3 (9.5) $W \cdot m^{-2}$, respectively.

The comprehensive data in experiment 2 giving the relations between TSR, T_{re} , and T_a at rest and at three different workloads (40, 60, and 80% $\dot{V}O_2$ max) at T_a of 30 and 40°C in summer and winter following prewarming are presented in fig 3. The thermoregulatory responses are described on the basis of the workloads (% of $\dot{V}O_2$ max) (fig 3A) and the T_a (fig 3B). At 30°C, TSRs at the various workloads were not significantly different between summer and winter after prewarming. At 40°C the results were similar. T_{re} had a control value of 37.17 (0.09)°C and 37.07 (0.09)°C at 30°C, and 37.23 (0.03) and 37.20 (0.12)°C at 40°C in summer and winter after prewarming, respectively. T_{re} did not change during the 20 min of exercise at 40% $\dot{V}O_2$ max at T_a of 30°C and 40°C in either season. At a T_a of 30°C and a workload of 80% $\dot{V}O_2$ max, T_{re} increased ($P < 0.05$), reaching values of 37.83 (0.17)°C in summer and 37.92 (0.10)°C in winter after prewarming. At a T_a of 40°C and a workload of 80% $\dot{V}O_2$ max, T_{re} increased ($P < 0.05$), reaching values of 37.79 (0.12)°C in summer and 37.90 (0.12)°C in winter after prewarming. There was no significant difference in T_{re} in summer and winter after prewarming at any workload at 40°C. However, T_s was higher in summer than in winter, in spite of the thermal stimulation. In the resting condition at 30°C, T_s values were 33.03 (0.16)°C ($n = 12$) and 34.05 (0.09)°C ($n = 12$) in winter and summer at 30°C, respectively. There were

Table 2 Seasonal variation of sweating responses during exercise. Values are means (SEM)

	Season				
	Winter	Winter with prewarming	Spring	Summer	Autumn
$\dot{m}_{sw}$ (g·min ⁻¹)	3.2 (0.4)†	5.0 (0.5)	4.2 (0.2)	5.2 (0.5)**	4.3 (0.2)
TSR (g·m ⁻² ·h ⁻¹)	108 (15.7)†	167 (17.2)	138 (14.9)	178 (26.2)**	142 (11.7)
Δ TSR (%)	-25.8 (4.3)	-	+1.9 (6.6)	+21.5 (5.0)**	+4.9 (4.5)
Δ TSR (%)*	-	+3.2 (6.4)	-9.0 (5.6)	+7.7 (5.0)	-6.4 (4.5)

$\dot{m}_{sw}$, mean sweat rate in a 20 min exercise; TSR, total sweat rate; Δ TSR, changing rate of against the annual mean value of TSR. *Based on data in winter with prewarming. The changing rate (Δ TSR) against the annual mean value of TSR during exercise for all four seasons was calculated by the following equation: Δ TSR = $(TSR_{ei} - TSR_{an})/TSR_{an} \times 100$, where TSR_{ei} = TSR during exercise in each season and TSR_{an} = the annual mean value of TSR. Significant difference from winter, * $P < 0.05$, ** $P < 0.01$. Significant difference from winter prewarming, † $P < 0.05$.

Fig 2 Rectal temperature (T_{re}) (A) and heat storage of the body (S) (B) caused by exercise at 40% $\dot{V}O_2$ max in the various seasons. W-PW, winter after pre-warming. Significant difference, a v a and b v b, $P < 0.05$.

significant differences between $\bar{T}_s$ in winter and summer ($P < 0.01$). Conversely, $\bar{T}_s$ at 40°C was significantly different in winter in comparison with summer, at 35.78 (0.11)°C ($n = 12$) v 35.13 (0.11)°C ($n = 12$), respectively. In all experiments T_s during exercise decreased by about 1°C at any workload. TSR and the level of $\bar{T}_s$ were dependent on T_a , and TSR and T_{re} were dependent on the workload.

Figure 4 shows the thermal balance in the control period and during exercise at T_a 30°C and 40°C in summer and winter after pre-warming. M was not significantly different in either season or temperature, but increased according to work intensity. At 30°C in summer and winter after prewarming, E was estimated at 31.1 (2.0) and 44.0 (6.6), 147.3 (14.0) and 143.6 (6.2), 216.3 (20.6) and 187.4 (4.2), and 288.9 (15.7) and 253.3 (25.8) $W \cdot m^{-2}$ at rest and at the three different

work intensities of 40%, 60%, and 80% $\dot{V}O_2$ max, respectively. At 40°C in summer and winter after prewarming, E was estimated 96.2 (4.0) and 80.9 (8.7), 210.0 (28.0) and 233.9 (8.7), 276.8 (5.4) and 292.3 (4.6), and 346.5 (11.3) and 305.8 (11.9) $W \cdot m^{-2}$ at rest and at the three different work intensities, respectively. E was not significantly different in summer and winter after prewarming ($F = 1.668$, $P > 0.05$, three way ANOVA, table 3). S was also not significantly different between summer and winter after prewarming ($F = 2.439$, $P > 0.05$, three way ANOVA, table 4). In both seasons, S levels peaked during exercise at 80% $\dot{V}O_2$ max and 30°C and 40°C. However, at a work intensity of 80% $\dot{V}O_2$ max, S in winter after prewarming was significantly higher than in summer. $R + C$ values were all negative at a T_a of 40°C, and there were significant differences between T_a 30°C and T_a 40°C, no matter

Table 3 Three way ANOVA table on the effects of season, workload, and ambient temperature (T_a) on evaporative heat loss

Source	df	Sum of squares	Mean square	F test	P value
Season (A)	1	967.505	967.505	1.668	0.2057
Workload (B)	3	367 088.592	122 362.864	211.017	0.0001
AB	3	3848.952	1282.984	2.213	0.1058
T_a (C)	1	52 794.7	52 794.7	91.046	0.0001
AC	1	282.755	282.755	0.488	0.49
BC	3	2203.507	734.502	1.267	0.3024
ABC	3	2395.022	798.341	1.377	0.2676
Error	32	18 555.88	579.871

Fig 3 Comparison of total sweat rate (TSR), rectal temperature (T_{re}), and mean skin temperature (T_{sk}) in summer (—) with that in winter following prewarming (---) at control (rest) and at three different workloads, 40%, 60%, and 80% of the individual's maximum oxygen uptake ($\dot{V}O_{2max}$) at 30° and 40°C. The thermoregulatory responses are described on the basis at the workloads (A) and the ambient temperatures (T_a) (B).

what degree the work intensity or whether summer or winter.

Discussion

Conflicting evidence has been presented on the effect of season on thermoregulatory responses during exercise,^{1 4 5 29} and previous reports have been unable to provide an adequate explanation for the mechanism and role of seasonal acclimatisation.

In experiment 1, the results show that the onset of sweat secretion in summer is markedly earlier than in winter. There was a significant difference in sweating patterns in the various seasons. In addition to its earlier onset, sweating also became more profuse in the warm season, even though the subjects were exercising under the same environmental conditions, as pointed out previously by Kuno.²⁰ Furthermore, Δ TSR, the change in the annual

mean total sweating rate, presented a typical pattern with summer high and winter low values, and the percentage deviation from the annual mean was +21.5 (5.0)% in summer and -25.8 (4.3)% in winter. The annual range of Δ TSR was reduced by prewarming in the cold season (table 2). We accept the concept proposed by Sasaki *et al*³⁰ to explain the mechanism of the annual periodicity of basal heat production in the Japanese. Clearly, the sweating rate, described as a relative value, can result in annual variation of sweating response under conditions of temperature and seasonal acclimatisation.

These results may imply that the sweating capacity and sensitivity in summer are greater than in winter, and there is natural seasonal acclimatisation of physiological function in humans to inhibit the dissipation of heat from the body in winter. In contrast, these functions may be attenuated in summer, in order to minimise heat storage by the body (fig 2B). The data from experiment 1 may reflect the fact that there is such a functional change in thermoregulatory mechanisms to seasonal temperature acclimatisation in the exercising human. We therefore compared thermal balance under submaximal exercise conditions in winter after prewarming and in summer.

The objective of experiment 2 was to assess whether m_{sw} and sweating sensitivity in the cold

Table 4 Three way ANOVA table on the effects of season, workload and ambient temperature (T_a) on heat storage of the body

Source	df	Sum of squares	Mean square	F test	P value
Season (A)	1	975.603	975.603	2.439	0.1282
Workload (B)	3	30 374.605	10 124.868	25.31	0.0001
AB	3	1164.945	388.315	0.971	0.4186
T_a (C)	1	279.367	279.367	0.698	0.4095
AC	1	632.201	632.201	1.58	0.2178
BC	3	546.618	182.206	0.455	0.7153
ABC	3	1944.614	648.205	1.62	0.204
Error	32	12 801.193	400.037

Fig 4 Thermal balance at rest (A, Control) and during exercise of 40% (B), 60% (C), and 80% (D) of $\dot{V}O_{2max}$ at T_a of 30°C and 40°C in summer (▨) and winter (□) after prewarming. M, metabolic rate; W, external work; H, total heat production; E, evaporative heat loss; R + C, radiative and convective heat loss; S, change in heat storage of the body.

Significant difference between summer and winter after prewarming, * $P < 0.05$; significant difference, † $P < 0.05$, T_a 30°C v T_a 40°C.

season can be enhanced by means of warming before exercise. The lack of seasonal difference in the sweating pattern during exercise in winter and summer when thermal stimulation of 30°C for 30 minutes (prewarming) was applied in winter was of interest. Many investigators⁷⁻¹⁰ have shown that enhancement of skin sweating results from physical training by an increase in the sensitivity of the skin

sweating response per unit of internal temperature rise, and heat acclimatisation by a decrease in sweating. It has been reported that during continuous exposure to severe heat, the sweating rate increases to a maximum.³¹ Nadel³² stated that during muscular activity, heat flows down the temperature gradient from the muscle to the body core and to the skin; that is, from where it can dissipate into the

environment. However, when environmental temperature is higher than skin temperature, heat transfers from the environment into the body. The rate of sweating becomes enhanced to meet the requirement of cooling when thermal stress and workload increase. Thermal stimuli evoke thermoregulatory responses that directly affect heat loss and heat production. Thus by prewarming we found that thermal stimulation helped the evaporation of sweat from the skin more in winter than in summer, showing an enhancement m_{sw} and sweating sensitivity in winter; in the cold season the evaporative losses are activated to the "summer type". This implies that operation of the heat dissipation centre in the hypothalamus may be induced through skin thermoreceptors activated by thermal stimulation.³³ Kuno²⁰ has suggested that changes in the sensitivity in the central nervous system may be most the important factor. However, repeatedly warming localised areas of the skin has been found to enhance sweating from the warmed areas,¹⁵ and it can be inferred that increase in sweating capacity is, at least in part, a peripheral effect caused by changes in the sweat glands. In addition, by local passive heating of the body surface, forearm blood flow and sweat gland activity in this region were markedly enhanced.^{34 35} Further studies are required to clarify these matters.

As previously reported by Hardy *et al*,³⁶ there were linear correlations between sweat rate and increase of rectal temperature, and sweat rate and the level of skin temperature (fig 3). The two major independent experimental variables in evaluating the effect of exercise on temperature regulation are the temperature of the environment and the workload. Our data illustrated in fig 3 show how these two variables cause changes in regulatory sweating, core temperature, and skin temperature. Saltin *et al*³⁷ showed that regulatory sweating can be predicted by a linear regression analysis with workload (or metabolic heat production) and ambient temperature, and these, taken together, represent the thermal load; this balance indicates the complete effectiveness of thermoregulation under these conditions. Benzinger³⁸ found that sweat rate was entirely dependent on the degree of elevation of the internal temperature, which he measured at the tympanic membrane, provided that mean skin temperature was above 33°C. The relation between the internal temperature and m_{sw} was the same, whether body temperature was raised by exposing the subject at rest to a hot climate or by metabolic heat production.

On the other hand, basal metabolism in Japan has been found to have seasonal variation, high in winter and low in summer.³⁹ Many researchers have investigated the effect of seasonal and other factors on heat production during exercise.^{1 2 4} According to Nielsen,⁴⁰ the rate of heat production caused by muscular exercise is more closely related to workload than to ambient temperature, and there is a significant correlation between increase in core temperature and in the rate of heat production. Moreover, Saltin and

Hermansen⁴¹ have shown that the increase in core temperature is proportional, not to the absolute value of metabolic rate, but to the relative workload, that is, to the percentage of the individual's $\dot{V}O_2$ max. It has previously been reported by Masuda²⁹ that heat production during exercise at a relative metabolic rate of 5 to 8 was not affected by season. Matsui *et al*³ have investigated $\dot{V}O_2$ max for each season in the year, and they found no significant relation with season. Although cardiac output, stroke volume, and heart rate were significantly decreased with higher ambient temperature (T_a 43.3°C), oxygen uptake during exercise was unaffected.⁴² In the present study, the workloads were 40%, 60%, and 80% of $\dot{V}O_2$ max throughout the year. Moreover, no circadian difference was observed in metabolic heat production, while workload level and circadian variation affected sweat rate, T_{re} , and mean body temperature.⁴³ Thus, assuming that metabolic heat production, for a constant work intensity, is at least at the same level in each season (fig. 4), the rise in the core temperature in summer may be considered to be similar to that in winter. We assumed that the thermal body warming conducted before exercise in the cold season activated the heat dissipating mechanisms. As stated above, our data suggest that sweating may be facilitated not only by a hypothalamic mechanism, from thermal information received from the skin thermoreceptors, but also by increased activity of the peripheral sweat glands.

Skin temperature control in humans has been shown to be the result of many factors.²³ The factors that affect the skin temperature are very complex and include core temperature, vasoconstriction and vasodilatation, blood flow, and ambient temperature (including the air velocity). In this study, we observed that an increased workload produced a proportional reduction in skin temperature in cool environments (10°C and 20°C). The fall in skin temperature is closely related to both non-thermal and thermal factors, such as evaporative heat loss.⁴⁴ However, in our study there was a fall in skin temperature during exercise at all workloads, and the fall was independent of the season and work intensity (figs 2 and 3). We also concluded that the skin temperature during exercise was modified as a result of competition between thermoregulatory vasodilatation and reflex induced vasoconstriction by regulatory factors imposed by the environmental temperature conditions. Nakayama *et al*^{45 46} have published a hypothesis on thermoregulatory mechanisms in the exercising human. If skin temperature does not change during physical exercise this is because of the competitive action between non-thermal vasoconstriction, thermal vasodilatation, and evaporation. On the other hand, if non-thermal vasoconstriction does not occur during exercise, internal temperature, with enhancement of heat dissipation function, does not increase through the exercise period. Thus the regulating mechanisms for increasing core temperature during physical exercise inhibit, at least in part, heat dissipation occurring by non-thermal

vasoconstriction due to the exercise. We agree with their hypothesis on thermoregulatory mechanisms during exercise.

Recently, the significance of exercise for a healthy life has been recognised worldwide but there is little practical knowledge about physiological thermoregulatory function in humans, especially as it is affected by temperature conditions and exercise. We determined that the maximum rate of sweating is controlled by both work intensity and humidity in moderate temperature conditions. The former contributes to reduced heat loss and the latter to increased metabolic heat production. The maximum sweating capacity in humans is observed in prolonged moderate muscular exercise under thermal stress, namely, internal and external heat loads.³¹ It is induced by 60 to 240 minutes of muscular activity such as walking in the desert and simulation of severe exercise (>80% of maximum aerobic capacity). Thus the exercising human is affected by seasonal factors, and in the prescription of exercise programmes attention must be paid to such factors as exercise intensity, frequency, and duration. Indeed, exercise performance is influenced by environmental temperature, since it represents an extra load on the circulatory and thermoregulatory mechanisms, but internal temperature affects physical performance as well.¹⁴ The beneficial effect of warm up has been known for a long time and was determined experimentally, for example, by Asmussen and Bøje,⁴⁷ who showed that the ability to perform running was better. Warm up has contributed to an increase in exercise performance and to a reduction in accidents caused by exercise and sports activity. This evidence may be important in evaluating the effectiveness of a physical training programme.

In conclusion, our findings suggest that adaptation of the thermoregulatory mechanisms during temperature and seasonal acclimatisation exists, and that external body warming enhances not only the heat dissipating activity of the thermoregulatory centre but also the induction of peripheral sweat gland activity. Furthermore, the seasonal change of m_{sw} in exercising men can be eliminated by prewarming in the cold season, suggesting a different type of acclimatisation. Our experimental results indicate that very rapid acclimatisation is possible.

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