

# Thermoregulation of exercising men in the morning rise and evening fall phases of internal temperature

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The purpose of this study was to compare the thermoregulatory responses during exercise in the morning rise (0900 h) and evening fall phases (2000 h) in circadian variation of body temperature. Five healthy volunteers performed bicycle exercises at 30% and 60% of maximal aerobic power ( $\dot{V}O_{2\max}$ ) at 26°C with a relative humidity of 50%. Whole-body sweat rate (SR), rectal ( $\bar{T}_{re}$ ), mean skin ( $\bar{T}_{sk}$ ) and mean body ( $\bar{T}_b$ ) temperature, pulmonary ventilation ( $\dot{V}_E$ ), oxygen uptake ( $\dot{V}O_2$ ), and carbon dioxide output ( $\dot{V}CO_2$ ) and heart rate (HR) were measured during the experimental period. SR during exercise at 30%  $\dot{V}O_{2\max}$  was significantly higher at 2000 h than at 0900 h. However, the circadian variation of SR during exercise was not observed at 60%  $\dot{V}O_{2\max}$ . At the two experimental times, there were also no significant differences in  $\dot{V}O_2$ ,  $\dot{V}CO_2$ ,  $\dot{V}_E$  and  $\bar{T}_{sk}$  in both workloads. In HR,  $\bar{T}_b$  and  $T_{re}$  circadian effects were demonstrated as well as in workload levels. As  $\bar{T}_b$  was plotted against SR during exercise, positive correlations were observed. The data showed that there was a parallel shift in the SR to  $\bar{T}_b$  relationship during exercise in the morning and evening. This rightward shift indicated that there was an increased  $\bar{T}_b$  threshold for the onset of sweating in the evening. Resting  $\bar{T}_b$  at 2000 h was significantly higher when compared with  $\bar{T}_b$  at 0900 h. The present results suggest that the circadian influence on the thermoregulatory response to exercise may be evident only at low workloads.

**Keywords:** temperature regulation, sweat rate, work intensity, circadian rhythm

The circadian rhythm in human body temperature appears to be regulated, rather than just the consequence of passive imbalances in the rate of heat production and heat loss<sup>1–4</sup>. Several of the following thermal physiological parameters to exercise and heat stress were shown to exhibit circadian rhythmicity: sweating<sup>5–8</sup>, skin blood flow<sup>5, 8, 9</sup>, body temperature<sup>5–8</sup> and heart rate<sup>10</sup>. Aschoff and Heise<sup>11</sup> estimated that in a resting man the circadian variations of heat loss were responsible for about 75% of the range of oscillation in internal temperatures, while the variation in heat production contributed only 25%.

Hirdebrandt<sup>12</sup> reported that the circadian control of human body temperature was the result of the following thermoregulatory adjustments: warming-up in the morning and cooling-down in the afternoon. However, identification of the factors that cause the circadian fluctuation has been more controversial.

It was previously reported by Niwa *et al.*<sup>6</sup> that there were a circadian rhythm of thermoregulatory response. Under the condition of an environmental temperature at 13°C with a relative humidity of 60%, the sweating response during bicycle exercise at workload of 450 kpm min<sup>-1</sup> (75 W) was at its maximum at 1800 h and its minimum at 0600 h, but heat production during exercise was identical at various periods during the day. However, no report was given on thermoregulatory response at different work intensities. The aim of the present study, therefore, was to investigate temperature regulatory responses at two different work intensities in the morning rise and evening fall phases in the human body temperature, and to discuss the circadian control mechanism contributed by the work factor.

## Materials and methods

### Subjects

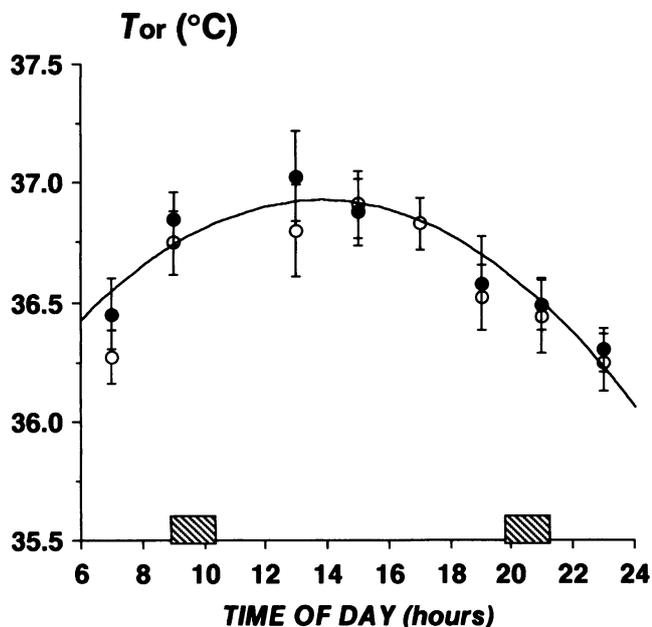
The subjects selected were five healthy male college students, mean(s.e.m.) age 21.6(0.7) years, 171.8(2.7) cm in height, 68.8(2.5) kg in weight, 1.83(0.04) m<sup>2</sup> of body surface area (= height<sup>0.178</sup> × weight<sup>0.427</sup> × 71.84 of Takahira's equation<sup>13</sup>), and with maximal aerobic power ( $\dot{V}O_{2\max}$ ) of 3.07(0.16) l min<sup>-1</sup> (mean(s.e.m.)). During the first visit to the laboratory, each subject was oriented to the basic equipment and procedures used in the experiment. Practice time was provided for riding the bicycle ergometer and performing the mouth piece for oxygen uptake ( $\dot{V}O_2$ ) measurement. Before the main experiments, each participant's  $\dot{V}O_{2\max}$  was determined by an incremental work rate protocol on a Monark bicycle ergometer using the Douglas bag technique<sup>14</sup>. The pedalling rate was kept constant at 50 rpm and timed with a metronome. After 2 min of pedalling with a constant load 720–780 kpm min<sup>-1</sup> (120–130 W), the work intensity was increased by 150 kpm min<sup>-1</sup> (30 W) every minute up to exhaustion. Before the main experiment, we

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also measured circadian variation of oral temperature in our subjects (Figure 1), and confirmed morning rise and evening fall in oral temperature.

**Experimental protocol**

The subjects arrived at the laboratory at least 1 h before the experiments, and sat quietly until the designated time. They undressed except for their



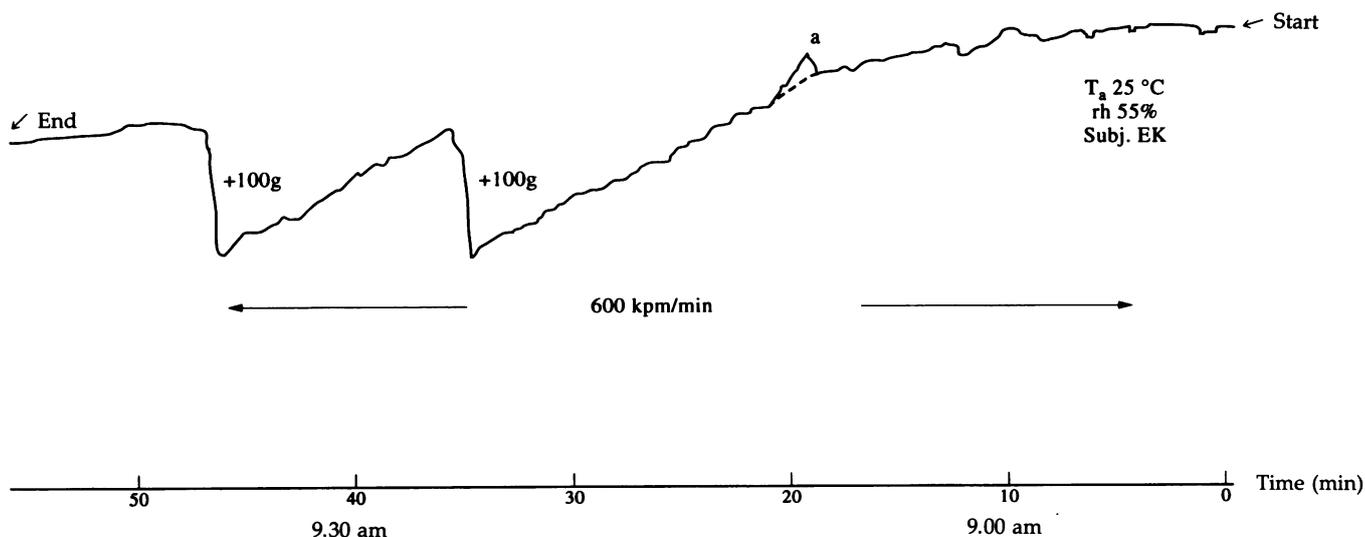
**Figure 1.** Circadian variations of mean oral temperature ( $T_{or}$ ) of resting subjects ( $n = 5$ ). Shaded areas represent the time period of the experiment. Resting oral temperature shows a diurnal increase and a nocturnal decrease, followed by an early morning increase. In the figure a quadratic line indicates its equation,  $y = 35.3 + 0.229x - 8.3160x^2$ ,  $r = 0.933$ .  $\circ$  = 1st measurement,  $\bullet$  = 2nd measurement. The periods of the present experiments are represented by two shaded areas

underwear. The experiments were done at two different times of the day, and each experiment was on a different day. The experiments were at 0900 h and 2000 h, with all studies starting within 30 min of the target time. The four experiments were carried out from October to early November, with the order randomized. The work intensities were both 30% and 60% of  $\dot{V}O_{2max}$  in each subject. After sitting on a chair for 30 min at the condition of thermoneutrality, they conducted a bicycle exercise for 40 min in a mean(s.d.) ambient temperature ( $T_a$ ) of 26°C(0.7°C) with a mean(s.d.) relative humidity (rh) of 50%(7.3%). An experimental work test was performed on 20 separate days, two at each of following times: 0900 h and 2000 h. No muscular work was performed for 24 h before any test. In the morning on an experimental day, the subjects conducted the cycle exercise without taking breakfast, and in the case of the experiments in the evening on another day kept no caloric intake six to eight h after taking lunch (usual foods) at 1300–1400 h.

**Measurements**

Sweating rate (SR) was measured continuously from whole body weight loss, using a bed scale (Model 33B, sensitivity,  $\pm 1.0$  g, J.A. Potter Co., Southington, Connecticut, USA) technique, as described previously<sup>15,16</sup>. The best curve shown in Figure 2 was drawn through the weight record for each experiment and rate of whole-body weight loss was then calibrated prior to each experiment. Respiratory evaporative weight loss was estimated by Mitchell *et al.*<sup>17</sup>.

The temperatures of four skin surface locations and rectum ( $T_{re}$ ) at a depth of 15 cm from the anus were recorded every 5 min by a copper-constantan thermocouple recording system (AM-300, Ohkura Electric Co. Ltd, Japan) with an accuracy of  $\pm 0.05^\circ\text{C}$  throughout the experimental period. Mean skin temperature ( $\bar{T}_{sk}$ ) and mean body temperature ( $\bar{T}_b$ )



**Figure 2.** A recording example of the whole body weight loss measured by a bed scale. After 15 min of exercise (at 100 W = 600 kpm min<sup>-1</sup>) the weight loss increased markedly. 100 g scales were indicated in the centre of a chart. The curve of weight losses was modified at the point a, because a thermocouple sensor dropped

were calculated from Ramanathan's<sup>18</sup> and Stolwijk-Hardy's<sup>19</sup> equations, respectively.

Heart rate (HR) was recorded by electrocardiography with a telemeter system (Model 270 and 1418, Sanei Sottki, Japan).  $\dot{V}O_2$  was determined by the Douglas bag technique at rest and during exercise, 5-, 10-, 20-, 30-, 40-min after the beginning of exercise and during recovery. The gas samples were immediately analysed for oxygen (F-3, Beckman Fullerman, California, USA) and carbon dioxide (MCD-L, Horiba Seisakusho, Japan). Expired gas volume was measured with a gas meter (WT-10, Shinagawa Seisakusho Co, Japan).

### Statistical analysis

Values represent the mean  $\pm$  s.e.m., and statistically significant differences of mean values were assessed by a paired *t* test and one-way ANOVA. We also evaluated time of day and work intensity to thermal response during exercise by means of two-way ANOVA. The significance of the regression line was also evaluated by covariance analysis. A probability level of 0.05 or less was accepted as a significant difference.

### Results

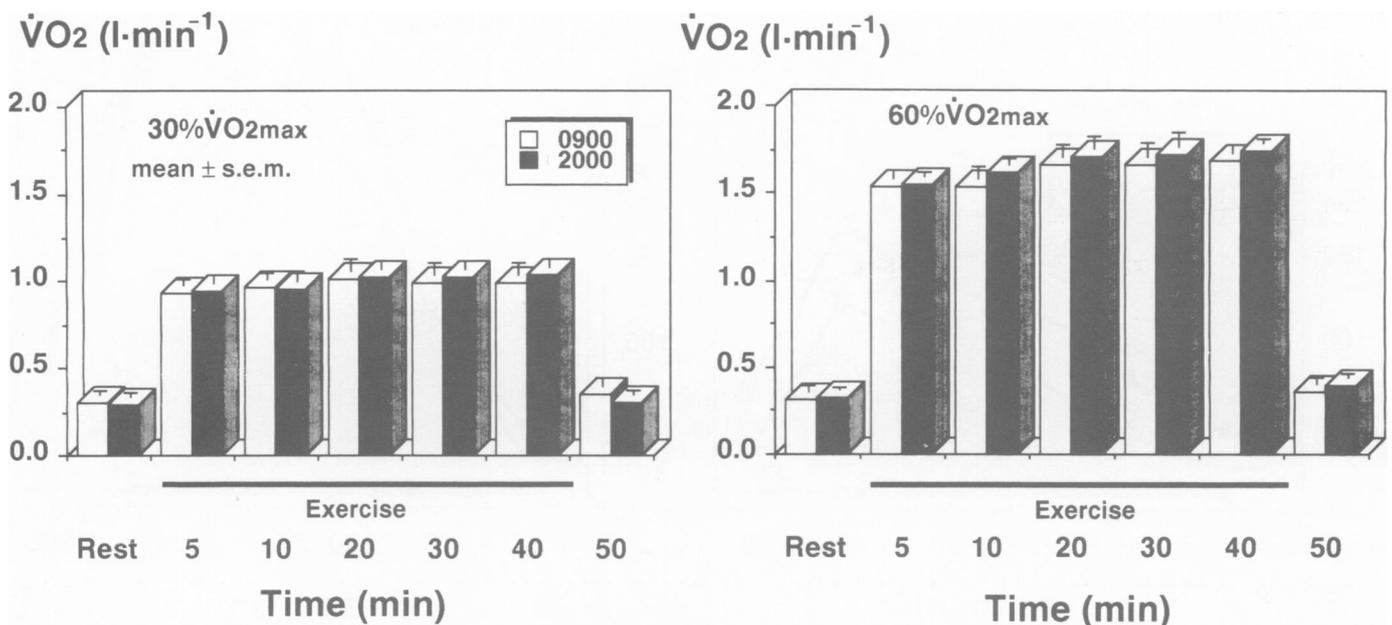
No individual differences were found among the subjects in all the data related to sweating responses at rest and during exercise ( $P > 0.05$ , one-way ANOVA).

Figure 3 shows the time courses of  $\dot{V}O_2$  during exercise at two different work intensities at 0900 h and 2000 h. While all subjects sat quietly on a bicycle ergometer, their mean (s.e.m.)  $\dot{V}O_2$  was not significantly different between 0900 h (309(19.2) ml min<sup>-1</sup>,  $n = 10$ ) and 2000 h (306(12.2) ml min<sup>-1</sup>,  $n = 10$ ). At the

end of the two test periods at 30%  $\dot{V}O_{2max}$  and 60%  $\dot{V}O_{2max}$ ,  $\dot{V}O_2$  measured during exercise averaged 1.000(0.06) and 1.611(0.06) l min<sup>-1</sup> and 1.041 (0.05) and 1.635 (0.03) l min<sup>-1</sup> ( $P > 0.05$ ), respectively. At all phases of the two test periods,  $\dot{V}O_2$  during exercise at 60%  $\dot{V}O_{2max}$  was significantly higher than 30%  $\dot{V}O_{2max}$  (two-way ANOVA). There were also no significant differences in carbon dioxide output and pulmonary ventilation in both workloads and at the conducted experimental time.

The time courses of HR during exercise at two different work intensities at 0900 h and 2000 h are represented in Figure 4. HR, at 25–40 min after the onset of exercise at 60%  $\dot{V}O_{2max}$ , was significantly higher at 2000 h than 0900 h. However, there was not a significant difference in the HR between 0900 h and 2000 h during exercise at 30%  $\dot{V}O_{2max}$ . At all phases of the two test periods, HR during exercise at 60%  $\dot{V}O_{2max}$  was significantly higher than 30%  $\dot{V}O_{2max}$  (two-way ANOVA).

The time courses of SR during exercise at two different work intensities at 0900 h and 2000 h are shown in Figure 5. SR during exercise at 30%  $\dot{V}O_{2max}$  (left), was significantly higher at 2000 h than 0900 h. At 60%  $\dot{V}O_{2max}$  exercise (right), SR was not significantly different, except for 20 min after the onset of exercise at 0900 h in comparison with 2000 h. At all phases of the two test periods, SR during exercise at 60%  $\dot{V}O_{2max}$  was significantly higher than 30%  $\dot{V}O_{2max}$  (two-way ANOVA). As shown in Table 1, at 30%  $\dot{V}O_{2max}$  exercise TSR and SR<sub>max</sub> were significantly higher at 2000 h than at 0900 h. In contrast, other parameters showed no significant differences between 0900 h and 2000 h in exercise at 60%  $\dot{V}O_{2max}$ . Furthermore, at 60%  $\dot{V}O_{2max}$  exercise, the time of reaching SR<sub>max</sub> was faster at 2000 h than at 0900 h ( $P < 0.01$ ), but there was not significant difference of the time of reaching SR<sub>max</sub> between 0900 h and 2000 h



**Figure 3.** Time courses of  $\dot{V}O_2$  in exercising men at two different workloads, about 30% [left] and 60% [right] of  $\dot{V}O_{2max}$  in the later morning [□] and evening [■]. Horizontal bars indicate an exercise period. Data represent mean (s.e.m.) for five subjects

in exercise at 30%  $\dot{V}O_{2max}$ . At rest insensible perspiration also was significantly higher at 2000 h and 0900 h (Table 1).

Figure 6 illustrates the time courses of  $T_{re}$  (top),  $\bar{T}_{sk}$  (middle) and  $\bar{T}_b$  (bottom) during exercise at two

different work intensities at 0900 h and 2000 h. Mean(s.d.)  $T_{re}$  had an initial value of 37.49(0.03)°C ( $n = 5$ ), and did not change during the 40 min of work at 2000 h (Figure 6, top and left). At 0900 h,  $T_{re}$  increased slightly reaching values of 37.17(0.12)°C ( $n = 5$ ) at

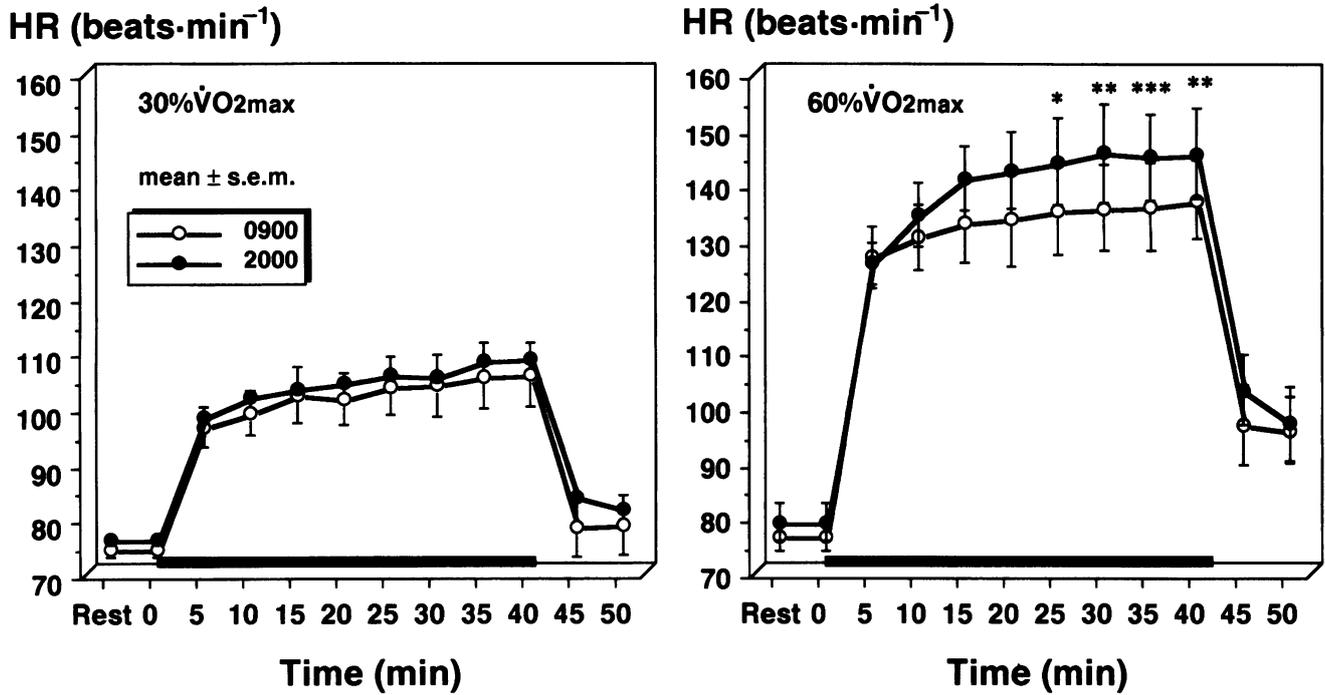


Figure 4. Time courses of HR in exercising men at two different workloads, about 30% [left] and 60% [right] of  $\dot{V}O_{2max}$  in the later morning [○] and evening [●]. Horizontal bars indicate an exercise period. Data represent mean(s.e.m.) for five subjects. Significantly different (paired *t* test), 0.900 h vs. 2000 h, \**P*<0.05, \*\**P*<0.01, \*\*\**P*<0.001

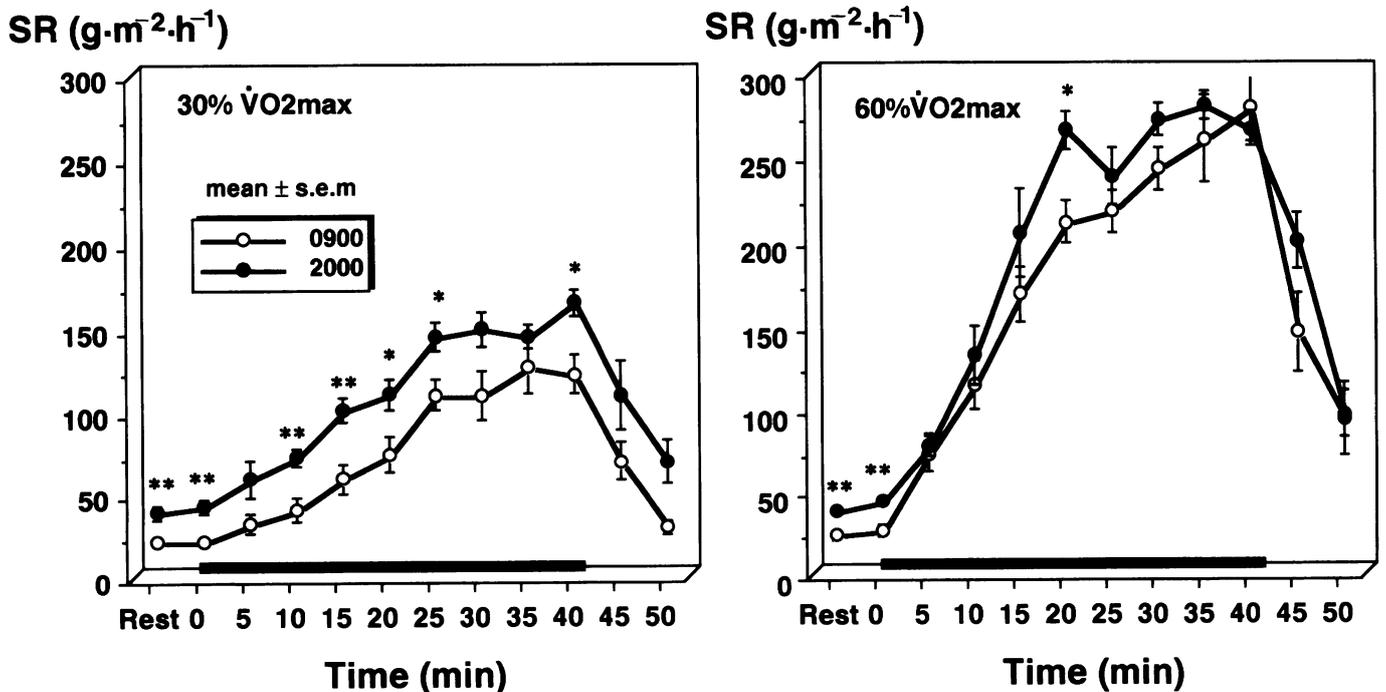


Figure 5. Time courses of SR in exercising men at two different workloads, about 30% [left] and 60% [right] of  $\dot{V}O_{2max}$  in the later morning [○] and evening [●]. Horizontal bars indicate an exercise period. Data represent mean(s.e.m.) for five subjects. Significantly different (paired *t* test) 0900 h vs. 2000 h, \**P*<0.05, \*\**P*<0.01

Table 1. Circadian variation of thermoregulatory responses in exercising men at two different work intensities

	30% $\dot{V}O_{2max}$		60% $\dot{V}O_{2max}$	
	0900 h	2000 h	0900 h	2000 h
TSR ( $g\ m^{-2}\ h^{-1}$ )	83.0(8.0)	117.3(2.8)*	194.4(8.7) <sup>†</sup>	216.2(11.0) <sup>†</sup>
SR <sub>max</sub> ( $g\ m^{-2}\ h^{-1}$ )	138.4(10.0)	167.4(6.1)*	283.4(17.1) <sup>†</sup>	287.4(5.2) <sup>†</sup>
TR SR <sub>max</sub> (min)	37(1.2)	33(3.0)	38(1.2)	29(2.4)**
$\Delta T_{re}$ (°C)	0.27(0.07)*	0.11(0.04)	0.70(0.10) <sup>†</sup>	0.61(0.02) <sup>†</sup>
$\Delta \bar{T}_{sk}$ (°C)	1.20(0.11)	1.42(0.36)	1.21(0.16)	0.85(0.02)
$\Delta \bar{T}_b$ (°C)	0.45(0.05)	0.37(0.09)	0.79(0.07) <sup>†</sup>	0.61(0.07) <sup>†</sup>

Data represent mean(s.e.m.) for five subjects; TSR, total sweat rate for 40 min of exercise; SR<sub>max</sub>, maximum rate of sweating during exercise; TR SR<sub>max</sub>, time of reaching SR<sub>max</sub> after the onset of exercise;  $\Delta T_{re}$ ,  $\Delta \bar{T}_{sk}$  and  $\Delta \bar{T}_b$ , changes from pre-exercise value in  $T_{re}$ ,  $\bar{T}_{sk}$  and  $\bar{T}_b$ , respectively; Significant difference (paired *t* test), 0900 h vs 2000 h, \**P* < 0.05, \*\**P* < 0.01; 30%  $\dot{V}O_{2max}$  vs 60%  $\dot{V}O_{2max}$ , <sup>†</sup>*P* < 0.01

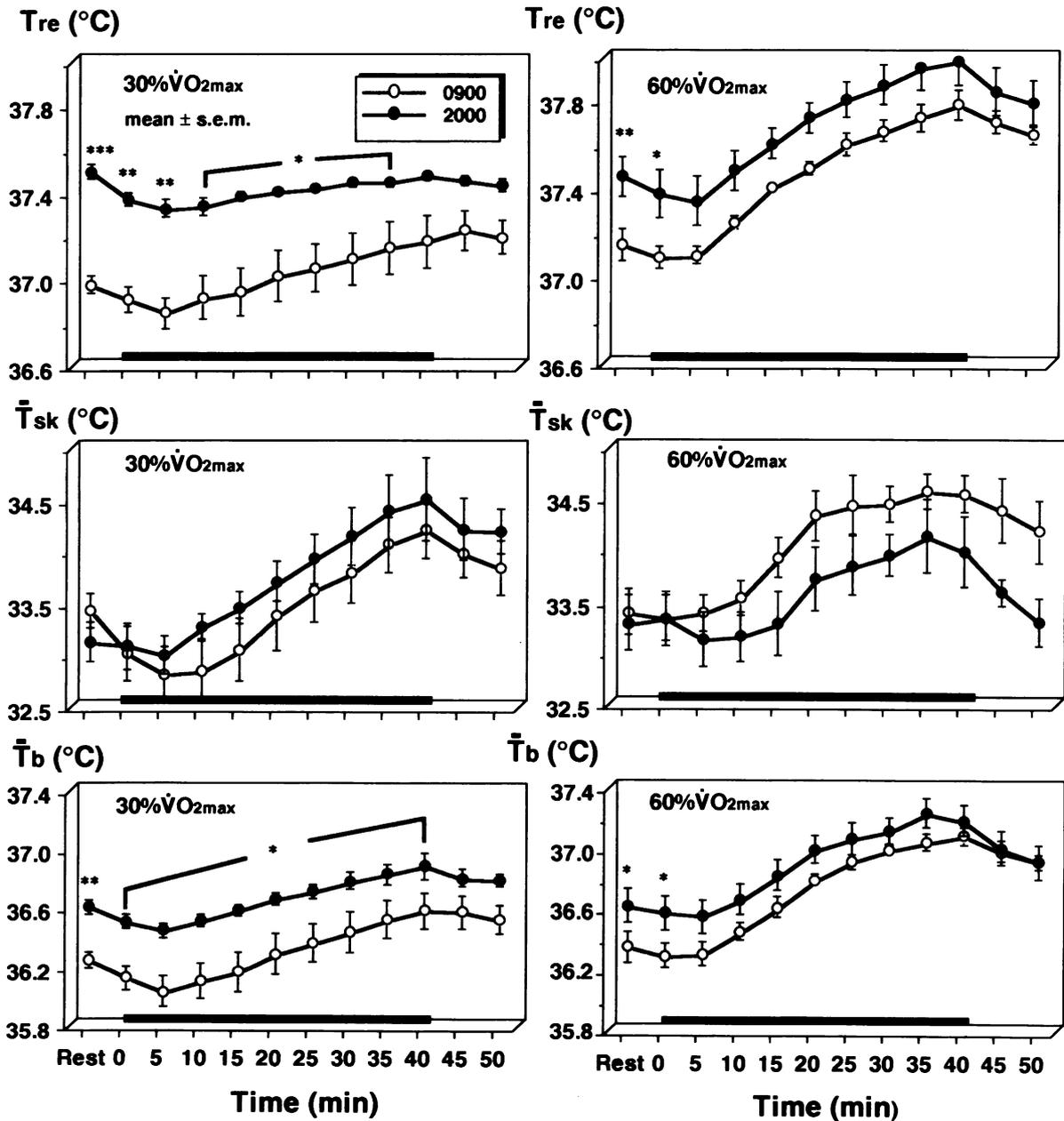


Figure 6. Time courses of  $T_{re}$ ,  $\bar{T}_b$  and  $\bar{T}_{sk}$  in exercising men at two different workloads, about 30% [left] and 60% [right] of  $\dot{V}O_{2max}$  in the later morning [O] and evening [●]. Horizontal bars indicate an exercise period. Data represent mean(s.e.m.) for five subjects. Significantly different (paired *t* test), 0900 h vs. 2000 h, \**P* < 0.05, \*\**P* < 0.01, \*\*\**P* < 0.001

40 min. There was no significant difference between  $T_{re}$  at 0900 h and at 2000 h, except for 40 min after the onset of exercise at 30%  $\dot{V}O_{2max}$  exercise. There was a significant difference in the rate of increase in  $T_{re}$  between 0900 h and 2000 h during exercise at 30%  $\dot{V}O_{2max}$ . In both periods,  $\bar{T}_b$  levels peaked during exercise at 60%  $\dot{V}O_{2max}$ . None of these changes were significant, suggesting no significant changes in  $\bar{T}_b$  during the exercise in both periods. However, at 30%  $\dot{V}O_{2max}$  exercise  $\bar{T}_b$  was significantly higher at 0900 h than at 2000 h. No significant difference in  $\bar{T}_{sk}$  was found between 2000 h and 0900 h in both workloads (Figure 6, bottom). After a transient fall,  $\bar{T}_{sk}$  slightly increased during exercise at the two different workloads of the two test periods. For sitting on a bicycle ergometer (at rest)  $T_{re}$  and  $\bar{T}_b$  also were significantly higher at 2000 h and 0900 h. There was no significant difference in  $\bar{T}_{sk}$  between 0900 h and 2000 h in the resting condition on a bicycle ergometer (Table 1).

As  $\bar{T}_b$  was plotted against SR during exercise, positive correlations were observed (Figure 7). In all

subject data concerning SR vs  $T_{re}$ ,  $\bar{T}_{sk}$  and  $\bar{T}_b$  relations (or the relation of SR to  $T_{re}$ ,  $\bar{T}_{sk}$  or  $\bar{T}_b$ ), the best correlation coefficient ( $r = 0.8201$ ) was observed in the SR vs  $\bar{T}_b$  relation. The regression equations and correlation coefficients are presented in Figure 7. Analysis of covariance revealed significant differences of the slope and intercept between the regression lines (SR vs  $\bar{T}_b$  relationship) at 0900 h and 2000 h to exercise at 30%  $\dot{V}O_{2max}$  ( $P < 0.05$ , respectively). At 60%  $\dot{V}O_{2max}$  exercise the intercept shifted to a higher temperature ( $P < 0.05$ ).

### Discussion

The circadian rhythm of different physiological and biochemical variations has been well established. A number of investigators studied the daily courses of SR<sup>5,6,8</sup>, peripheral blood flow<sup>5,8,9</sup>,  $\dot{V}O_{2max}$ <sup>20</sup> and HR<sup>10</sup> in muscular working humans. A nocturnal lowering human core temperature has been correlated with a lowering to the core temperature threshold for cutaneous vasodilation and sweating during exercise<sup>5</sup> and rest to a heat exposure<sup>21</sup>. Timbal *et al.*<sup>7</sup> investigated at 0200 h, 1000 h and 1800 h during a heat exposure of 90 min, sweat rate, body temperature and heat storage of the body of human subjects. According to their calculating and measuring data, the relationship between the change of heat storage of the body ( $\Delta S$ ) in the morning and that during the night is expressed in the following equation:  $\Delta S_{night} = 0.69S_{morning} - 6.24$ . In the present study, SR during exercise at the lower work intensity was significantly higher in the evening than in the morning. In this case, we were in agreement with the previous reports<sup>6,8</sup>. However, the circadian variation of SR during exercise was not observed at the heavy work intensity. In the previous studies, there was no comparison made of the effects of work intensity on the circadian control to temperature regulation. In the present study  $T_{re}$  and  $\bar{T}_b$  at rest (values before exercise) were significantly higher at 0900 h than 2000 h. From our data, it suggests that heat dissipating activity in the central control system is activated more in the evening than in the later morning.

At the heavy workload, the HR of exercising men in the evening was significantly higher than that in the later morning.  $\dot{V}O_2$ , however, increased in proportion to workloads, not to time of day (two-way ANOVA). No measurements were made of other physiological parameters in cardiorespiratory function. The present study suggests that, for cardiorespiratory function and skin circulation during exercise, the regulatory system circulation may be modified by the work factors. Cohen and Muehl<sup>10</sup> reported that there was circadian variation of HR during submaximal exercise. In resting HR, they also noted 50 beats  $min^{-1}$  at 0400 h and 70 beats  $min^{-1}$  at 1800 h during the time of day. We, however, did not observe HR in a resting condition, and did not compare directly with their subject laying (supine) on a bed, because our subjects were seated on a bicycle ergometer. Further studies are required to measure other physiological parameters such as cardiac output, stroke volume and skin blood flow.

A typical rightward shift in  $\bar{T}_b$  threshold for SR was

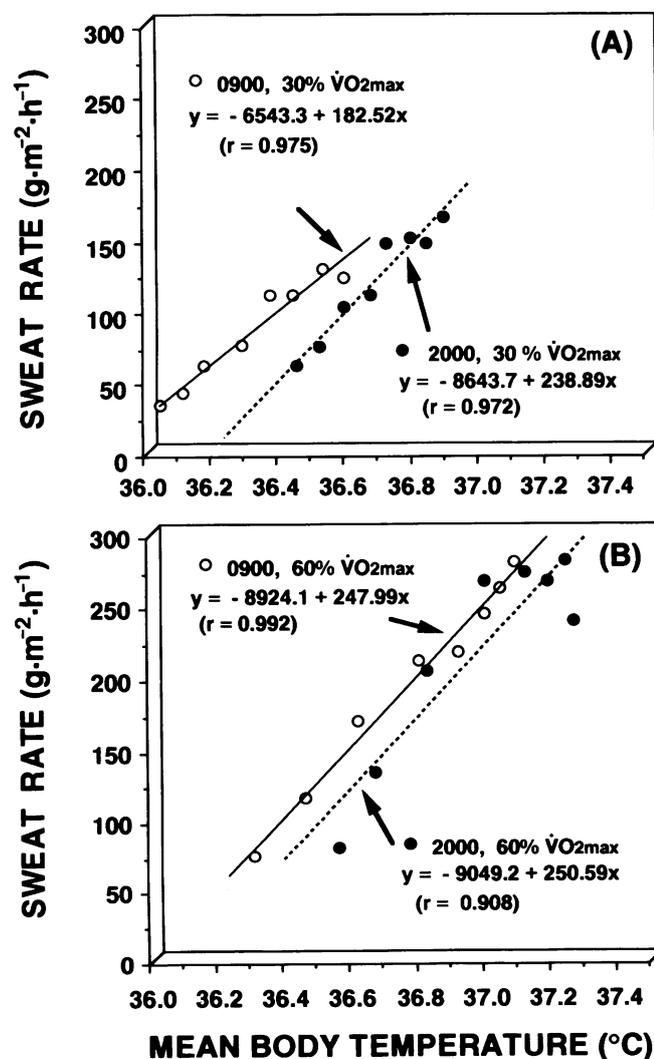


Figure 7. Relationship between SR and  $\bar{T}_b$  in exercising men at two different workloads 30% [A] and 60% [B] of  $\dot{V}O_{2max}$  in the later morning [O] and evening [●]. SR and  $\bar{T}_b$  were mean values during exercise for five subjects

shown in the data (Figure 7). SR was graphed as a function of  $\bar{T}_b$  during two different exercises in the morning and evening. The data showed that there was a parallel shift (rightward) in the SR to  $\bar{T}_b$  relationship during exercise in the later morning and evening. This rightward shift indicated that there was an increased  $\bar{T}_b$  threshold for the onset of sweating in the evening. The increased threshold temperatures for sweating and vasodilation, observed by Stephenson *et al.*<sup>8</sup>, were affected by the normal circadian rhythm in resting internal temperature. In our experiment, resting  $\bar{T}_b$  in the evening was significantly higher ( $P < 0.001$ ) in comparison with that in the later morning. This result supported the concept that the regulation of sweating is related to a critical level of  $\bar{T}_b$  or heat storage of the body<sup>22</sup>. In another study<sup>23</sup>, the regulation of sweating was analysed in terms of the interaction between central and peripheral inputs to the thermoregulatory system. Inputs from the skin thermosensors stimulated by the rate of change in skin temperature, have been shown to play a major role in the regulation of sweating in exercising subjects<sup>24</sup>.

Although core temperature is the primary thermoregulatory drive in the control of skin sweating, skin temperature can also affect SR<sup>24</sup>. In the present study, however, there were no significant differences in skin temperature in the exercising men at two different work intensities in the later morning and the evening. These data suggest that skin temperature shifted the minimum levels to maximum levels in the early morning, or the maximal levels to the minimum levels in the afternoon, if we accept Hildebrandt's hypothesis<sup>12</sup> on circadian control in human thermoregulation; that is, circadian regulatory mechanisms change to warming-up after 0300 h and the regulatory function change to cooling-down after 1500 h. Examining the effect of a step change in environmental temperature upon the skin temperature and blood flow of a seated human, Sasaki and Carlson<sup>25</sup> observed that the circadian change of core temperature was paralleled by variations in both skin temperatures and peripheral blood flows. They have reported cycles in the heat dissipating responses which are not readily explained by simultaneous changes in core temperature. On the other hand, the rise in core temperature of an exercising man was proportional to work intensities and largely independent of ambient temperatures between 5–30°C. This rise in core temperature was not due to a failure in body temperature regulation, but was attributed to the setting of the body thermostat at a higher level<sup>26,27</sup>. At the same work intensity, our data differ in the rate of increase of core temperature presented by  $T_{re}$  due to exercise between the later morning and evening (Table 1). Moreover, evaporative cooling indexes as TSR,  $SR_{max}$  and the time to reach  $SR_{max}$  did differ markedly by means of work intensity (Figure 5 and Table 1); that is, TSR and  $SR_{max}$  during exercise at the heavy workload did not observe the circadian variation.

Furthermore, our data indicate that the two major independent experimental variables in evaluating the effect of exercise on temperature regulation are the condition of the internal environment such as the

'biological clock'<sup>28</sup> and the workload. Figures 5 and 6 show how these two variables cause changes in regulatory sweating, core temperature and skin temperature. In the cooling-down period, heat dissipation activity was stimulated compared to the warming-up period at the lower workload. However, effector responses dissipating heat at the heavy workload are not distinguished in both phases.

It has been reported that in an exercising human the thresholds for sweating moved toward a lower core temperature early in the morning (0400 h)<sup>5</sup>. On the other hand, in the present study a tendency was observed in humans for the changes in core temperature during thermal transient caused by exercise to be larger at the later morning phase than at the evening phase. The rise in core temperature in a man during heat and cold exposure was reported to be higher at early morning (0200 h) than later morning (1000 h) and evening (0600 h)<sup>7</sup>. These findings may reflect the fact that the thermosensitivity of an exercising man is reduced during the night. As illustrated in Figure 7, the slopes of the temperature characteristic lines might also be reduced as indicated by temperature sensitivity during the light phase in addition to the parallel shifts mentioned above. This could cause a further downward shift of set-point temperature from day to evening.

Recently, the significance of exercise prescription for a healthy lifestyle has been recognized<sup>29</sup> but there is little practical knowledge about the physiological-thermoregulating functions in humans, especially as affected by internal conditions<sup>28</sup>. Many works<sup>30–32</sup> have reported that the risk factors for coronary heart disease decrease with an increase in aerobic exercise and sports (or muscular activity). Thus, an exercising man is affected by the time of day, and prescribers of exercise programmes must pay attention to factors such as exercise intensity. These findings are applicable to practical-exercise activity; that is, our data may be important in planning the practice of and in evaluating the effectiveness of a physical exercise programme.

In conclusion, the results of this study indicate that the circadian control of thermoregulatory response to exercise may be modulated by the workloads in the later morning and evening. It is suggested that the rise in human body temperature normally observed during exercise at the light workload in the later morning is due partly to the proportional nature of the circadian control mechanism and partly to the lower level in sweating which locally inhibits the heat dissipating responses due to evaporating sweat. These findings seem to have important implications for further research; for example, disappearance or lowering of the circadian variation in sweating response to exercise at the higher work intensity. The circadian variation of thermal regulation during exercise may be modulated by this factor.

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