# HEAT BALANCE REGULATION DURING EXERCISE: CIRCADIANITY AND SEASONALITY

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## INTRODUCTION

Recent reviews of the literature on thermoregulation during exercise including the regulation of thermal sweating have been made by many scientists [see (1) for Jessen's review]. Human body temperature is determined by the balance between heat accumulation, whether generated by physical activity (metabolic heat production) or gained from the environment (environmental heat), and heat dissipation. Heat storage is, thus, the result of either excessive heat accumulation or reduced ability to dissipate body heat. In human exercise-thermoregulation, there exist physiological variables affected by his internal and environmental factors (2-6). The purpose of the present study is to investigate heat balance during exercise under controlling seasonal and circadian variations.

## GENERAL METHODS AND PROCEDURES

All subjects were untrained males who had not participated in any regular physical conditioning for at least several years preceding the experiment, and had not been heat acclimated (Table 1). No muscular work was performed for 24 h before **any** test. In the morning on an experimental day, the subjects conducted cycle exercise without taking breakfast, and in the case **of** the experiments in the evening on another day kept no kaloric intake six to eight hours after taking lunch (usual foods) at 1300-1400 h.

All experiments were carried out in a climatic chamber whose environmental temperature ($T_a$) was maintained at **26,** 30 or 40°C, and relative humidity (rh) at a constant from 45 % to **55** %. Wind velocity in the climatic chamber was controlled at about **0.8** $m \cdot s^{-1}$. The subjects performed bicycle (Monark) exercise at various work intensities. The bicycle ergometer was placed on a Potter bed scale. Sweat rate (SR), rectal ($T_{re}$) and skin temperatures and oxygen uptake ($VO_2$) were measured simultaneously. The SR was monitored continuously using a bed scale (J. **A.** Potter, Model 33B) with an automatic electronic weight change indicator. In experiment II heart rate (HR) was recorded by electrocardiography with a telemeter system (Model 270 and 1418, San-ei **Sottki).** In order to estimate metabolic heat production (*M*), oxygen consumption was determined by Douglas bag technic at rest and during exercise and recuvery. The $T_{re}$ and four or seven skin temperatures were recorded spontaneously every minute by a copper-constantan thermocouple recording system (AM-300, Ohkura Co.). Mean skin temperature ($T_{sk}$) and mean body temperature ($T_b$) were calculated from Ramanathan's or Hardy-DuBois' method and Stolwijk-Hardy's method, respectively. The thermoequilibrium under the different phases of energy expenditure was calculated by following equation (7):

$$H = M - W = E + E_{res} \pm (R + C) \pm S \qquad (W \cdot m^{-2})$$

where: H = total heat production; *M* = metabolic rate; W = external work; E = evaporative heat loss; $E_{res}$ = evaporation due to respiratory tract; $R+C$ = radiative and convective heat loss; *S* = heat storage of the body.

## EXPERIMENT I

### Procedures

We undertook the exercise tests at four different energy expenditures (rest, 40%, 60% and 80%$VO_{2max}$) in the hot season (August) and the cold season (February). Subjects arrived at the laboratory abetween 8:00 and 8:30 am, and rested at least 30 min on a chair at a natural room temperature (28°C) in the hot season or at a warmed room temperature (30°C) in the cold season. Succsessively, they exercised by a bicycle ergometer for 20 min after sitting on it for 10 min in both seasons.

### Results and Discussion

E at the various work loads in summer and winter were not significantly different. At 40°C the results were similar to those above (three-way ANOVA, $F[1, 32]=1.688$, $P=0.2057$). $T_{re}$ had a control value of 37.17±0.09°C and 37.07M.09 "C at 30°C, and 37.23M.03 and 37.20±0.12°C at 40°C in summer and winter, respectively. $T_{re}$ did not change during the 20 min of exercise at 40%$VO_{2max}$ at 30 and 40°C in either season. At 30°C at a work load of 80%$VO_{2max}$, $T_{re}$ increased (un paired t-test, $P<0.05$) reaching values of 37.83±0.17°C in summer and 37.92 ±0.10°C in winter. At 40°C at a work load of 80%$VO_{2max}$, $T_{re}$ increased ($P<0.05$) reaching values of 37.79±0.12°C in summer and 37.90±0.12°C in winter. There was no significant difference in $T_{re}$ at any work loads in summer or winter. In the resting condition at 30°C, $T_{sk}$s were 33.03±0.16°C (mean±SEM, n=12) and 34.05±0.09°C (n=12) in winter and summer at 30°C, respectively. There were significant differences between $T_{sk}$ in winter and summer ($P<0.01$). Conversely, $T_{sk}$ at 40°C was significantly different in winter (35.78±0.11°C, n=12) in comparison with summer (35.13±0.11°C, n=12). In either case, E and the level of $T_{sk}$ were dependent on the $T_a$, and E and $T_{re}$ were dependent on the work loads (Fig. 1).

## EXPERIMENT II

### Procedures

We undertook the exercise tests at two different work intensities (30% and $60\% VO_{2max}$) in the morning rise (0900 -) and evening fall (2000 -) phases of the human body temperature. After sitting on a chair for 30 min at the condition of thermoneutrality (26°C), subjects conducted a bicycle exercise for **40** min in an $T_a$ of 26°C with a rh of 55%. The four experiments were carried out form October to early November, with the order randomized.

### Results and Discussion

Figure 2 shows a typical example of the time courses of SR, $T_{re}$ and $T_{sk}$, V02 and HR during exercise at two different work intensities at 0900 and 2000. SR during exercise, at 38% $VO_{2max}$, was at all stages higher at 2000 than 0900. At 65% $VO_{2max}$ exercise, SR was same level at 0900 in comparison with 2000. $T_{re}$ at before exercise was slightly higher at 0900 than 2000. At ***65%*** $VO_{2max}$, HR of exercising men in the evening was finally higher than that in the later morning. $VO_2$, however, increased in proportion to work loads, not to time of day.

At all stages, the values of *M* and H showed no significant difference between morning and evening. As shown in Fig. 3, E during exercise at $30\% VO_{2max}$ (left), was significantly higher at 2000 than 0900. At 60% $VO_{2max}$ exercise (right), E was not significantly different, except for 20 min after the onset of exercise at 0900 in comparison with 2000. At all phases of the two test periods, E during exercise at $60\% VO_{2max}$ was significantly higher than at $30\% VO_{2max}$ (one-way ANOVA, F [1, 18]=73.65, P=0.0001).

**As** $T_b$ was plotted against E during exercise, positive correlations were observed (Fig. **4**). The regression equations and correlation coefficients (*r* ) were presented into the Figure **4.** Analysis co-variance revealed a significant difference of the slope between the regression lines at 0900 and 2000 at the lower work intensity. This rightward shift indicated that there was an increased mean body temperature threshold for E in the evening. In resting conditions, $T_b$ in the evening were significantly higher (paired t-test, $P < 0.001$) in comparison with that in the later morning.

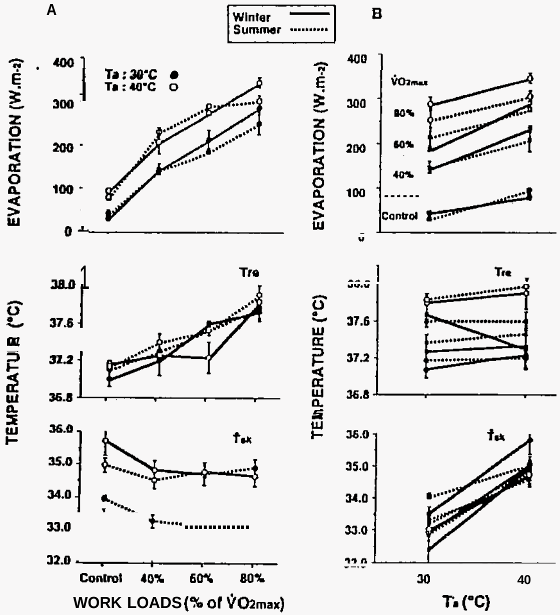



Figure I: Comparison of evaporative heat loss (Q. rectal temperature ($T_{re}$) and mean skin temperature ($\bar{T}_{sk}$) in summer with that in winter at control (rest) and at three different work intensities. 40, 60 and 80% $\dot{V}O_{2max}$ (maximal oxygen uptake) at 30 and 40°C. The thermoregulatory responses are described on the basis at the work intensity *(A)* and the $T_a$ (6).

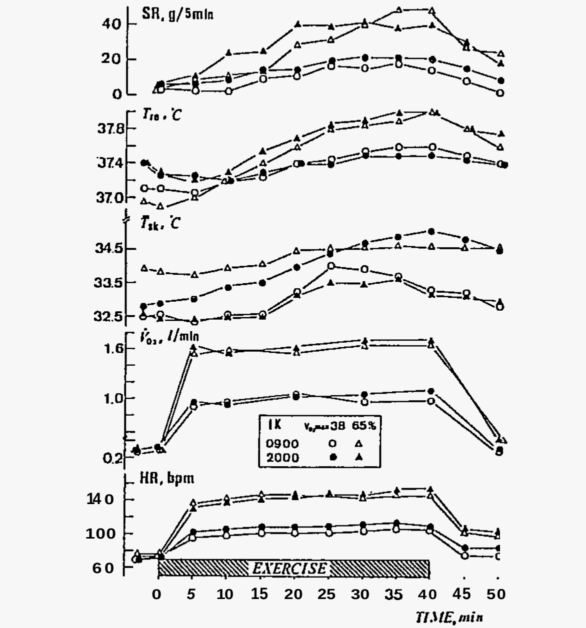



Figure 2: Time courses of sweat rate (SR), recta temperature ($T_{re}$), mean skin temperature ($\bar{T}_{sk}$), oxygen uptake ($\dot{V}O_2$) and heart rate (HR) in exercising man at two different work loads, about 38 % [circles] and 65 % [triangles] of $\dot{V}O_{2max}$ (maximal oxygen uptake) in the morning [open symbols] and evening [closed symbols]. A typical example of *Subject 4* (IK). Environmental conditions, an ambient temperature ($T_a$) 26°C and a relative humidity (rh) 55 %, are identical in each experiment.

Table I: Physical characteristics of the subjects and their work loads

| | Subj. No. | Age (yrs) | Ht (cm) | Wt (kg) | BSA $(m^2)^a$ | $\dot{V}O_{2max}$ $(ml \cdot kg^{-1} \cdot min^{-1})^b$ | Work Loads (walls) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 28 | 165 | 63 | 1.70 | 43.7 | 60 | 90 | 125 |
| Exp. 1 | 2 | 28 | 166 | 68 | 1.77 | 38.5 | 60 | 90 | 125 |
| | 3 | 22 | 167 | 55 | 1.62 | 51.4 | 80 | 110 | 140 |
| | 4 | 23 | 162 | 63 | 1.68 | 43.2 | 50 | 100 | |
| | 5 | 23 | 172 | 75 | 1.89 | 36.2 | 45 | 90 | |
| Exp. 2 | 6 | 22 | 172 | 71 | 1.85 | 50.3 | 60 | 110 | |
| | 7 | 19 | 178 | 75 | 1.94 | 44.9 | 50 | 100 | |
| | 8 | 21 | 175 | 65 | 1.80 | 45.0 | 50 | 100 | |

[a] Body surface area was estimated by Takahira's equation. b Maximal oxygen uptake ($\dot{V}O_{2max}$) determined from an incremental exercise test on a bicycle ergometer.

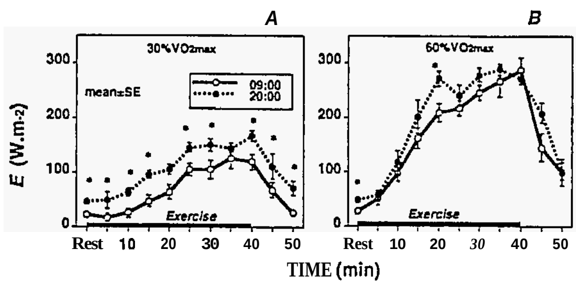
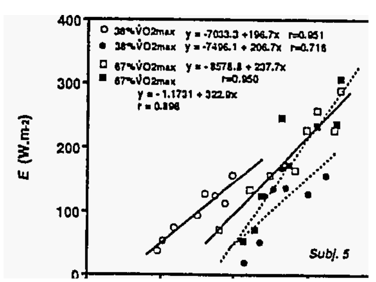



Figure 3 Time courses of evaporative heat loss ($E$) in exercising men at two different work loads. about 30 % [A] and 60 % [B] of $\dot{V}O_{2max}$ (maximal oxygen uptake) in the morning [open circles] and evening [closed circles].



## CONCLUSION

From Experiment I: The work loads were 40, 60 and 80% of the individual's $VO_{2max}$ throughout the year. Thus, assuming that metabolic heat production, for a constant work load, is at least at the same level for each season, the elevations in the core temperature and *S* in summer may be considered to be similar to that in winter. We have previously investigated seasonal change of thermal responses by means of a mild thermal stimulation (30°C for 30 min) before a moderate exercise in winter (7, 8). It was found that the thermal stimulation helped evaporative cooling response more in winter than in summer, showing the enhancement of sweating sensitivity in winter. Because there was no seasonal change of heat balance in exercising humans, in the cold season the evaporative cooling response due to skin sweating is activated to "summer type".

From Experiment 11: The results of this study indicate that the circadian control of thermoregulatory response to exercise may be modulated by the work loads in the later morning and the evening. These observations are in good agreement with the results from the previous reports (9-11). Evaporative cooling response in exercising men could be enhanced more in the evening than in the later morning. There is the circadian variation of evaporative cooling response, "evening-higher and morning-lower".

Acknowledgements: We would like to express our gratitude to our colleagues Prof. T. Sasaki, Prof. H. Nakayama and Dr. M. Yamasaki and their contributions to the experimental work presented here. We also thank Dr. M. Orleans, Visiting Professor in the Kyushu Institute of Technology, for checking the English.

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