Effects of menstrual cycle and physical training on heat loss responses during dynamic exercise at moderate intensity in a temperate environment

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Submitted 11 August 2004; accepted in final form 24 January 2005

Kuwahara, Tomoko, Yoshimitsu Inoue, Miyako Abe, Yuki Sato, and Narihiko Kondo. Effects of menstrual cycle and physical training on heat loss responses during dynamic exercise at moderate intensity in a temperate environment. Am J Physiol Regul Integr Comp Physiol 288: R1347–R1353, 2005. First published January 27, 2005; doi:10.1152/ajpregu.00547.2004.—We evaluated the effects of the menstrual cycle and physical training on heat loss (sweating and cutaneous vasodilation) responses during moderate exercise in a temperate environment. Ten untrained (group U) and seven endurance-trained (group T) women (maximal O2 uptake of 36.7 ± 1.1 vs. 49.4 ± 1.7 ml·kg−1·min−1, respectively; P < 0.05) performed a cycling exercise at 50% maximal O2 uptake for 30 min during both the midfollicular and midluteal menstrual phases. The sweating rate and cutaneous blood flow were significantly higher during the midluteal than during the midfollicular phase (P < 0.05). Sweating rate and cutaneous blood flow (measured via laser-Doppler flowmetry on the chest, back, forearm, and thigh) were lower during the midluteal than during the midfollicular phase during exercise. Tc threshold for heat loss responses was significantly higher and sensitivity of the heat loss responses was significantly lower in the midluteal phase than in the midfollicular phase, regardless of body site. These effects of the menstrual cycle in group U were not observed in group T. The sweating rate and cutaneous blood flow were significantly higher in group T than in group U, regardless of menstrual phase or body site. Tc threshold for heat loss responses was significantly lower and sensitivity of heat loss responses was significantly greater in the midluteal phase than in the midfollicular phase; however, sensitivity of the sweating response was significantly greater in the midfollicular phase. These results suggest that heat loss responses in group U were inhibited in the midluteal phase compared with in the midfollicular phase. Menstrual cycle had no remarkable effects in group U, plasma levels of estrone, estradiol, and progesterone at rest and esophageal temperature (Tes) during exercise were significantly lower and sensitivity of the heat loss responses was significantly lower in the midluteal phase than during the follicular phase (14, 15, 17, 18, 23, 31, 33, 35). In addition, the rise in the core body temperature threshold for sweating and cutaneous vasodilation during the luteal phase is mainly due to elevated progesterone concentrations (8, 31).

Conversely, there are conflicting reports on the effects of the menstrual cycle on the sensitivities for sweating and cutaneous vasodilation, i.e., the slope of the relationship between core body temperature and heat loss responses (14, 15, 23, 31, 33, 35). No marked differences in the sensitivities of the sweating and cutaneous vasodilation responses on the forearm were observed between the phases of the menstrual cycle during exercise at 60–85% of maximal O2 uptake (V̇O2max) in a hot environment (ambient temperature of 35–50°C) (23, 31, 33, 35). In addition, the sensitivities of the sweating responses on the chest and forearm were similar in both phases of the menstrual cycle during exercise at 50% V̇O2max in a temperate environment (ambient temperature of 25°C, relative humidity of 50–55%) (14). By contrast, Grucza et al. (15) reported that sweating responses on the chest and back were more sensitive in the luteal phase than in the follicular phase during exercise at 50% V̇O2max in a similar temperate environment. Although these studies indicate that the menstrual cycle does not influence the sensitivity of the heat loss responses during high-intensity exercise in hot environmental conditions, the effect of the menstrual cycle on the sensitivity during moderate-intensity exercise in temperate conditions is debatable. The mean skin temperature and forearm blood flow during moderate exercise in an ambient temperature of 28°C have been shown to be lower in the luteal phase than during menstruation, although this difference was not observed at 35°C or 48°C (19). This suggests that intense heat stress during exercise (or intense environmental conditions) masks the effects of the menstrual cycle on heat loss responses under moderate heat stress. Moreover, the plasma volume associated with the sensitivity of heat loss responses (25) is lower in the luteal phase than in the follicular phase (30, 32, 34). Therefore, we hypothesized that the sensitivity of the heat loss responses during moderate exercise differs according to the phase of the menstrual cycle to a greater degree in a temperate environment than under intense heat stress (23, 31, 33, 35).

In general, long-term physical training improves the sweating and cutaneous vasodilation responses, although studies have focused mainly on men (2, 21). Among long-term physiologically trained women, the sensitivity of the heat loss responses during moderate exercise (50% V̇O2max) was significantly greater in the midluteal than during the follicular phase (14, 15, 17, 18, 23, 31, 33, 35). In addition, the rise in the core body temperature threshold for sweating and cutaneous vasodilation during the luteal phase is mainly due to elevated progesterone concentrations (8, 31).
ically trained men, the time to onset of sweating and cutaneous vasodilation is shorter (1, 12) and the sweating rate (SR) and cutaneous blood flow are higher at a given core body temperature than among untrained men (2, 21, 38). The higher SR in the long-term physically trained man was achieved via enhanced peripheral mechanisms, such as changes in the sensitivity of the sweating response and sweat gland activity (1, 7, 38). Among long-term physically trained women, the fluctuations in female hormone levels are smaller than those in untrained women (5, 6, 10, 11), and this is associated with a smaller difference in core body temperature. Therefore, the thresholds for sweating and cutaneous vasodilation should not change markedly with the menstrual cycle in trained women; however, thresholds in untrained women would be expected to be associated with a higher core body temperature in the luteal phase, compared with that in the follicular phase. We hypothesized that long-term physical training in women might improve the sensitivity of heat loss responses during both menstrual cycle phases, paralleling the results in men (1, 7, 38).

To date, no study has investigated the influences of physical training on heat loss responses during exercise in trained women with regard to the menstrual cycle. Therefore, the purpose of this study was to examine the effects of the menstrual cycle on heat loss responses in young untrained women during moderate-intensity exercise in a temperate environment. In addition, to investigate the effects of physical training on the responses to exercise-induced heat stress, we compared heat loss responses of young healthy untrained women with the responses of long-term physically trained women during moderate-intensity exercise in a temperate environment.

METHODS

Subjects. Ten healthy, young, untrained women (group U) and seven young, physically trained women (group T) volunteered to participate in this study. Except for gymnastics lessons, group U subjects had not performed regular physical activities for the previous 3 yr, but group T had participated in endurance sports (e.g., long- or middle-distance running) for longer than 6 yr. No subjects took oral contraceptives, which contain female hormones, and all subjects had self-reported regular menstrual cycles of ~28 days. Their physical characteristics are presented in Table 1. No differences in age, height, mass, or ratio of skin surface area to mass were observed between groups U and T, but group T had a significantly lower mean skinfold thickness and significantly higher VO2max than group U, with a 34.6% difference between groups. The purpose and procedures of the study were explained to the subjects before their informed consent was obtained. This study was approved by the Human Subjects Committee of our department at Kobe University.

Protocol. Each subject performed the exercise test in the midfollicular phase (6–9 days after the onset of menstruation) and in the midluteal phase (6–9 days before the onset of menstruation). Test days were determined from daily measurements of basal body temperature and were confirmed by measuring plasma concentrations of estrone, estradiol, and progesterone after the exercise tests (Table 2). The test order was assigned randomly, and a nearly equal number of subjects began the test in the midfollicular and midluteal phases. The experiment was started at 9:00 or 14:00. To prevent the circadian rhythm of the core body temperature from affecting the results, all tests were performed at the same time of day for each subject. Tests were conducted during the season that presented minimal effects of heat acclimatization.

Table 1. Physical characteristics in all subjects

<table>
<thead>
<tr>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Mass, kg</th>
<th>AD/MASS, cm²/kg</th>
<th>MSF, mm</th>
<th>VO2max, ml/min·kg⁻¹</th>
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<td>2.5</td>
<td>5.0</td>
<td>0.9</td>
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</table>

AD/mass, surface area-to-mass ratio; MSF, mean skinfold thickness of 7 sites (see text); VO2max, estimated maximal O2 uptake. *Significantly different between untrained group (group U) and trained group (group T), P < 0.05.

Each subject reported to the laboratory and changed into a sports bra, panties, and shorts. Each subject’s height, mass, and skinfold thickness were measured, and each entered the environmental chamber at an ambient temperature of 25°C and relative humidity of 45%. The subject rested for 60 min in a semi-reclining chair mounted behind a cycle ergometer while the measurement devices were applied. After baseline measurements were taken for 5 min, the subject performed the cycling exercise in the semi-supine position at 50% VO2max for 30 min, while maintaining a pedaling frequency of 50 rpm.

Measurements. Body surface area was calculated from height and mass using the method of Fujimoto and Watanabe (13), and body fatness was assessed as the mean value of the skinfold thickness measured with skinfold calipers over the chest, flank, back, triceps, front of the forearm and thigh, and back of the lower leg. The VO2max for each subject was estimated in a submaximal step-load bicycle exercise test performed on a day other than those of the exercise tests. An intravenous blood sample (5 ml) was taken from the antecubital vein before the exercise test. Plasma estrone, estradiol, and progesterone concentrations in blood samples from each woman were measured with the use of commercially available radioimmunoassay kits (estrone RIA, Diagnostic Systems Laboratories; Coat-A-Count estradiol, Diagnostic Products; Coat-A-Count progesterone, Diagnostic Products) after all of the exercise tests. The ranges of hormone concentrations in the radioimmunoassays were as follows: 15–66 and 17–129 pg/ml for estrone, 11–82 and 9–230 pg/ml for estradiol, and less than 1.7 and 0.2–31.6 ng/ml for progesterone in the follicular and luteal phase, respectively. The intra- and interassay variations were 3.08–9.38% and 5.36–8.75% for estrone, 4.22–9.96% and 2.29–6.97% for estradiol, and 3.86–10.5% and 2.27–3.81% for progesterone, respectively.

Esophageal temperature (Te) and local skin temperature (Tsk) were measured continuously at nine different sites (forehead, chest, abdomen, back, forearm, hand, thigh, lower leg, and foot). Te was monitored with a copper constantan placed in poly tubing. The tip of the tube was advanced a distance equal to one-fourth of the subject’s
Table 2. Plasma levels of estrone, estradiol, and progesterone

<table>
<thead>
<tr>
<th></th>
<th>Estrone, pg/ml</th>
<th>Estradiol, pg/ml</th>
<th>Progesterone, ng/ml</th>
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<td>Group U</td>
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<tr>
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<tr>
<td>SE</td>
<td>2.7</td>
<td>6.4</td>
<td>3.6</td>
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</table>

Group T

|        |                |                 |                     |                 |               |                 |
| 11     | 16.3          | 25.9            | 18.6                | 28.7            | 0.2           | 0.4             |
| 12     | 13.9          | 19.5            | 10.0                | 31.5            | 0.6           | 2.1             |
| 13     | 12.9          | 65.0            | 10.0                | 102.0           | 0.2           | 0.3             |
| 14     | 24.3          | 24.7            | 20.5                | 32.0            | 0.4           | 0.4             |
| 15     | 27.6          | 28.1            | 21.2                | 21.0            | 0.2           | 0.9             |
| 16     | 27.3          | 32.5            | 27.2                | 45.5            | 0.4           | 4.4             |
| 17     | 19.3          | 33.2            | 24.8                | 81.5            | 0.5           | 4.1             |
| Mean   | 20.2          | 32.7            | 18.9                | 48.9            | 0.36          | 1.80†           |
| SE     | 2.3           | 5.7             | 2.5                  | 11.6            | 0.06          | 0.67            |

F, midfollicular phase; L, midluteal phase. *Significantly different from midfollicular phase of the menstrual cycle, P < 0.05. †Significantly different between groups U and T, P < 0.05.

standing height from the external nares. We monitored 
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S 
 recorded every 15 s with a data logger (Takara Thermistor data logger), and the data were stored in a personal computer (Epson PC-286LS).

Local SR was measured on the chest, back, forearm, and thigh using the ventilated capsule method. Dry nitrogen gas was supplied to the capsules (10.17 cm
2
) at a rate of 1.5 l/min. The humidity of the nitrogen gas flowing out of the capsules was measured with a capacitance hygrometer (Vaisala HMP 133Y). We monitored cutaneous blood flow at the chest, back, and forearm using laser-Doppler flowmetry (LDF; Advance ALF21). Each probe was placed on a skin site near the respective sweating capsule, taking care to avoid placing the end of the optical fiber directly over a superficial vein or hair follicle. SR and LDF were recorded at sampling rates of 50 Hz, and data were stored in a personal computer (Apple Computer, Power Macintosh 7600/200) via a data logger (BIOPAC Systems, MP 100WS). Both parameters were calculated as average values for 1 min.

The density of active sweat glands (ASG) and the sweat output per gland (SGO) measured on the chest, back, and forearm were determined 25–27 min after the start of the exercise. We determined the ASG density at a site adjacent to the sweat capsule using the starch-iodide technique (20) and calculated SGO at the respective sites by dividing the mean SR for 3 min (25–27 min) by the number of ASG. The same observer carefully determined the ASG density in all tests.

Heart rate (HR) was measured continuously with an electrocardiogram. Systolic and diastolic blood pressures were determined every 5 min by brachial auscultation, using an autosphygmomanometer (Speidel and Keller). Mean arterial pressure (MAP) was calculated as

\[ \text{MAP} = \frac{(\text{systolic} + 2 \cdot \text{diastolic blood pressure})}{3} \]

The cycle exercise was continued for 5 min after the main exercise test was completed, and 
O
2
 uptake (V
O
2
) was measured.

Data analyses and statistics. Because the MAP did not markedly differ across the conditions, we used LDF (which was measured continuously) as an index of cutaneous blood flow. All LDF values during the exercise test were converted to percentages of the baseline value [\%LDF = (LDF/baseline LDF) \times 100]. In addition, we calculated the mean values of SR and \%LDF for each body site to evaluate whole body responses of these variables.

To characterize the differences in the sweating and cutaneous vasodilation responses between midfollicular and midluteal phases in group U and between groups U and T in each menstrual cycle phase, regression equations were calculated for each subject during exercise for 
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 vs. SR and for 
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 vs. %LDF. The sensitivity of heat loss responses (regression slopes) was defined as the duration (time) of exercise during which rapid increases in 
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, SR, and %LDF were observed. The data collected after 
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 reached a steady level were not included in the linear regression equation. The 
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 thresholds for the sweating and cutaneous vasodilation responses were defined as the 
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 at the initiation of sweating and a rapid increase in cutaneous blood flow, respectively.

We also determined the thresholds for heat loss responses by calculating the liner regression between 
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 and heat loss responses, where %LDF = 100 and SR = the baseline SR value. Because both methods for detection of thresholds produced the same results (see below), we used the former method in this study.

A two-way ANOVA was performed to assess group or menstrual cycle effects for physical characteristics, female hormone concentrations, and thresholds and sensitivities of heat loss responses. A two-way ANOVA with repeated measures was used to analyze the effects of time and phase of the menstrual cycle or fitness level. Data are presented as means ± SE. A P value < 0.05 was considered statistically significant.

RESULTS

Effects of menstrual cycle in group U. The plasma levels of estrone, estradiol, and progesterone were significantly higher in the midluteal phase than during the midfollicular phase in group U (Table 2). Baseline 
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E
S 
 was significantly higher during the midluteal phase. By contrast, baseline HR, MAP, and 
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A
K 
 (Fig. 1) and 
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 on the chest, back, forearm, and thigh did not differ markedly between the menstrual cycle phases. During exercise, 
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 and the change in 
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) were significantly higher during the midluteal than during the midfollicular phase. The difference in 
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 according to the menstrual cycle was greater after exercise than at rest. Moreover, 
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 on the back was significantly higher in the midluteal phase than in the midfollicular phase in group U during exercise. The menstrual cycle had no effect on HR, MAP, and 
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 (Fig. 1), as well as on 
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 at the end of exercise (1,015 ± 39 and 990 ± 43 ml/min in midfollicular and midluteal phase, respectively).

SR and %LDF during exercise were significantly lower in the midluteal phase than in the midfollicular phase in group U (Fig. 2). Figure 3 shows the relationship between 
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 and the mean values of SR and %LDF, and Table 3 presents the 
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 thresholds and sensitivities of the sweating and cutaneous vasodilation responses. The 
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 thresholds of SR and %LDF were significantly higher during the midluteal phase than during the midfollicular phase. The sensitivities of the sweating and cutaneous vasodilation responses were significantly smaller during the midluteal phase than during the midfollicular phase. These heat loss responses were similar at all body sites.
ASG density on the forearm was significantly lower during the midluteal than during the midfollicular phase. However, ASG density at the other sites and SGO were not affected by the menstrual cycle in group U.

Effects of physical training. No effects of the menstrual cycle on the female hormone, cardiovascular, and thermoregulatory parameters were observed in group T. There were no significant differences in the estrone, estradiol, and progesterone levels between groups U and T during the midfollicular phase of the menstrual cycle. By contrast, during the midluteal phase, the plasma progesterone concentration was significantly lower in group T than in group U (Table 2).

Although no remarkable difference was observed in the baseline T_{es} during the midfollicular phase between the two groups, the T_{es} of group T was significantly lower during the midluteal phase. The baseline HR was significantly lower in group T than in group U, regardless of menstrual cycle phase. No marked differences were observed between the two groups for baseline MAP, T_{sk} (Fig. 1), or T_{sl} in either phase of the menstrual cycle. During exercise, T_{es} was significantly lower in group T than in group U during the midluteal phase; however, T_{es} did not differ between the two groups during the midfollicular phase. The ΔT_{es} was significantly greater in group T than in group U, regardless of menstrual cycle phase. No notable differences in HR, MAP, and T_{sk} (Fig. 1) or T_{sl} during exercise were observed between the two groups during either menstrual cycle phase. At the end of the exercise, V_{O2} was significantly greater in group T than in group U during both phases (for group T, 1,251 ± 56 and 1,249 ± 56 ml/min in midfollicular and midluteal phase, respectively; for group U, see above).

![Fig. 1. Time courses of heart rate (HR), mean arterial blood pressure (MAP), esophageal temperature (T_{es}), and mean skin temperature (T_{sk}) during a cycling exercise at 50% maximal O_{2} uptake (V_{O2} max) in untrained (U) and trained (T) women under the same experimental conditions during the midfollicular (F) and midluteal (L) phase of the menstrual cycle. Values are means ± SE. *Significantly different from midfollicular phase of the menstrual cycle, P < 0.05. †Significantly different between groups U and T, P < 0.05.](image1)

![Fig. 2. Changes in the mean values of the sweating rate (SR) and skin blood flow (measured as laser-Doppler flowmetry in percent; %LDF) during a cycling exercise at 50% V_{O2} max in group U and group T under the same conditions during the midfollicular and midluteal phases. Values are means ± SE. *Significantly different from midfollicular phase of the menstrual cycle, P < 0.05. †Significantly different between groups U and T, P < 0.05.](image2)
SR and %LDF during exercise were significantly higher in group T than in group U (Fig. 2). During the midfollicular phase, the $T_{es}$ thresholds of SR and %LDF did not differ between the two groups. By contrast, during the midluteal phase, the $T_{es}$ thresholds of SR and %LDF were significantly lower in group T than in group U. The sensitivity of the sweating response was significantly greater in group T than in group U during the midfollicular phase. During the midluteal phase, the sweating response sensitivity was significantly greater in group T than in group U. The sensitivity of cutaneous vasodilation was significantly greater in group T than in group U during the midluteal phase but not during the midfollicular phase (Fig. 3 and Table 3). These heat loss responses were similar at all body sites.

Table 3. Esophageal temperature threshold for sweating and cutaneous vasodilation (Threshold $T_{es}$), and the sensitivities of heat loss responses

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</table>
| Group U
| 1  | 36.95 | 37.44 | 0.91 | 0.37 | 37.08 | 37.62 | 319 | 250 |
| 2  | 36.93 | 37.22 | 0.62 | 0.30 | 37.01 | 37.16 | 420 | 274 |
| 3  | 36.89 | 36.97 | 1.65 | 0.73 | 37.05 | 37.24 | 1,936 | 419 |
| 4  | 36.94 | 37.31 | 1.21 | 1.02 | 37.18 | 37.47 | 1,802 | 631 |
| 5  | 37.26 | 37.49 | 0.88 | 0.72 | 37.33 | 37.49 | 380 | 255 |
| 6  | 37.33 | 37.60 | 0.52 | 0.73 | 37.39 | 37.62 | 319 | 116 |
| 7  | 37.02 | 37.80 | 0.89 | 0.73 | 36.99 | 37.73 | 534 | 385 |
| 8  | 36.70 | 37.44 | 0.87 | 0.84 | 36.66 | 37.29 | 337 | 174 |
| 9  | 37.65 | 37.18 | 0.40 | 0.04 | 36.58 | 37.08 | 301 | 169 |
| 10 | 37.18 | 37.30 | 0.48 | 0.31 | 37.31 | 37.31 | 159 | 80 |
| Mean | 37.00 | 37.38* | 0.84 | 0.58* | 37.03 | 37.40* | 705 | 283* |
| SE | 0.07 | 0.07 | 0.12 | 0.10 | 0.09 | 0.07 | 221 | 49 |
| Group T
| 11 | 36.93 | 36.62 | 2.02 | 0.50 | 37.11 | 37.10 | 455 | 336 |
| 12 | 37.22 | 37.31 | 1.13 | 0.94 | 37.21 | 37.32 | 583 | 325 |
| 13 | 36.84 | 37.30 | 1.35 | 1.49 | 36.89 | 37.36 | 1744 | 1261 |
| 14 | 36.80 | 37.68 | 1.42 | 1.59 | 37.01 | 37.03 | 834 | 1140 |
| 15 | 36.82 | 37.01 | 0.89 | 1.26 | 36.97 | 36.99 | 895 | 827 |
| 16 | 37.25 | 37.30 | 1.23 | 1.10 | 37.00 | 37.18 | 762 | 468 |
| 17 | 37.06 | 37.25 | 0.80 | 1.09 | 37.06 | 37.13 | 407 | 194 |
| Mean | 36.99 | 37.10† | 1.26† | 1.14† | 37.04 | 37.16† | 811 | 650† |
| SE | 0.07 | 0.11 | 0.15 | 0.14 | 0.04 | 0.05 | 171 | 161 |

Values are mean of each body site. Lack of data in subject 10 of group U was because cutaneous blood flow during midfollicular phase did not increase markedly from baseline. *Significantly different from midfollicular phase of the menstrual cycle, $P < 0.05$. †Significantly different between group U and T, $P < 0.05$.

**DISCUSSION**

The main findings of this study were as follows. First, in group U, the thresholds of sweating and cutaneous vasodilation during moderate cycling exercise in a temperate environment were significantly higher, and the sensitivities of heat loss responses were significantly lower, during the midluteal phase than during the midfollicular phase. However, ASG density and SGO did not differ markedly with the menstrual cycle in group U. Second, the effects of the menstrual cycle on heat loss responses in group U were not observed in group T. Furthermore, physical training improved heat loss responses: the thresholds were lower and the sensitivities were greater in group T during the midluteal phase. The improvements in the heat loss responses of group T were more remarkable during the midluteal phase than during the midfollicular phase. These aforementioned findings apply to all sites of the body that were measured in this study.

**Effects of the menstrual cycle in group U.** To our knowledge, this is the first study to show that the sensitivities of the sweating and cutaneous vasodilation responses during the midluteal phase are significantly lower than those during the midfollicular phase in untrained women during moderate exercise in temperate conditions. This observation is not in agreement with other studies. Fukuoka et al. (14) reported that the sensitivity of the sweating response did not change during...
the menstrual cycle. By contrast, Gruca et al. (15) showed that the sensitivity of the sweating response during the luteal phase was greater than during the follicular phase. This disagreement between earlier studies and the present study may have resulted, in part, from differences in the experimental conditions, including differences in exercise position [Fukuoka et al. (14) and Gruca et al. (15) exercised their subjects in an upright position], indexes of core body temperature (the earlier studies used rectal temperature), or in the physical characteristics of the subjects. Previous studies have suggested that $T_{es}$ is a better index with which to evaluate heat loss responses than rectal temperature (17, 18, 28, 36). Therefore, our results may be more accurate than those of earlier studies in which rectal temperature was used to evaluate sensitivity of the core temperature (14, 15).

Various factors influence the sensitivity of heat loss responses (25–27, 29, 37). First, it has been reported that a decrease in $T_d$ is associated with a decrease in the sensitivity of heat loss response (26). However, our results suggested that the lower sensitivities of heat loss responses in the midluteal phase are not due to a change in $T_d$ because there was no marked difference in $T_d$ between either phases of the menstrual cycle. Second, an increase in exercise intensity has been reported to decrease the sensitivity of heat loss responses (29, 37). Given that $V\dot{O}_2$ at the end of the exercise was not influenced by menstrual cycle in group U and that the subjects exercised at the same absolute intensity in both exercise tests in our study, exercise intensity was not responsible for the change in the sensitivities of heat loss responses in this study. In addition, it has been reported that $V\dot{O}_2$ max does not change during the menstrual cycle (15, 24). Third, a reduction in plasma volume decreases the sensitivity of heat loss responses via the unloading of cardiopulmonary baroreceptors (25, 27). This inhibition can be caused by only a slight reduction in blood volume (−200 ml) (27). Stephenson and Kolka (34) showed that plasma volume decreases by an average of 210 ml during the luteal phase, compared with that during the follicular phase. Moreover, Stachenfeld et al. (30, 32) reported that plasma volume is decreased 200–300 ml by endogenous and exogenous increases in estradiol and progesterone concentrations. Therefore, the declines in the sensitivities of heat loss responses during the luteal phase that we observed are likely to be attributable to a reduction in plasma volume.

Our results differ from those of earlier studies that reported no marked difference in the sensitivities of heat loss responses between menstrual cycle phases during exercise at $60–85\% V\dot{O}_2$ max in hot environments (ambient temperatures between 35 and 50°C) (23, 31, 33, 35). Horvath and Drinkwater (19) reported that forearm blood flow was lower during the luteal phase than during menstruation during exercise at $30\% V\dot{O}_2$ max in a temperate environment (28°C), whereas this difference was not observed at 35 or 48°C. Moreover, Crandall (9) suggested that an increase in core body temperature reduces the baroreflex control of vasomotor tone. These reports imply that greater heat stress resulting from high-intensity exercise or hot conditions masks the effect of the menstrual cycle on the sensitivity of heat loss responses. This may explain why the effects of the menstrual cycle on the sensitivities of heat loss responses that we observed were inconsistent with the results of earlier studies (23, 31, 33, 35).

**Effects of physical training.** In this study, although female hormone concentrations were not significantly increased during the midluteal phase relative to the midfollicular phase in group T, the concentrations of these hormones were within normal ranges. Individually, three of the seven trained women (subjects 11, 13, and 14) had lower progesterone concentrations in the midluteal phase. However, even these three women had regular menstruation. Moreover, physical training has been shown to reduce female hormone levels, and thus the lower hormone concentrations in group T perhaps was an effect of training (6). Therefore, we included these three women in our investigation of the effects of physical training on heat loss responses.

Although $\Delta T_{es}$ was significantly greater in group T than in group U, lower $T_{es}$ thresholds and greater sensitivities of heat loss responses were observed in group T than in group U during the midluteal phase when we examined the relationship between $T_{es}$ and heat loss responses. These differences do not seem to be the result of differences in $T_d$ and $T_b$ between the two groups, which could have affected the thresholds or sensitivities of heat loss responses (26) because $T_d$ and $T_b$ did not markedly differ between the two groups, irrespective of menstrual cycle phase. In addition, $V\dot{O}_2$ at the end of exercise and the absolute exercise intensity were significantly greater in group T than in group U. However, it has been reported that the threshold of the cutaneous vasodilation response was increased and the sensitivity was decreased by an increase in exercise intensity (29, 37). Therefore, as lower $T_{es}$ thresholds and greater sensitivity of the heat loss responses occurred in group T, these differences in threshold and sensitivity could not be explained by group differences in only $V\dot{O}_2$ or absolute exercise intensity.

The SR and cutaneous blood flow for a given core body temperature in men increase with long-term physical training (2, 21, 38). A higher SR is achieved in long-term physically trained men via enhanced peripheral mechanisms, such as the sensitivity of the sweating response and sweat gland activity (1, 7, 38). The group differences in the thresholds and sensitivities for heat loss responses in the midfollicular phase in this study might reflect the same effects of physical training on women that occur in men (2, 21, 38), as there were no marked differences in the concentrations of female hormones between groups U and T. During the midfollicular phase, the thresholds of both heat loss responses did not differ between the two groups. Moreover, no effect of physical training on the sensitivity of the cutaneous vasodilation response was observed during the midfollicular phase. By contrast, the sensitivity of the sweating response was significantly greater in group T during the midfollicular phase. Therefore, in women, physical training might have a greater effect on the sweating response than on cutaneous vasodilation.

Our data suggest that the greater differences in heat loss responses between the two groups during the midluteal phase in the present study are related to the diminished fluctuation in female hormone secretion in group T. Specifically, given that female hormones inhibit heat loss responses (4, 19, 22), the diminished female hormone concentrations during the midluteal phase in group T may have compounded the effects of physical training. Because increases in progesterone concentrations are associated with a reduction in plasma volume (30, 32), plasma volume in group T was probably not markedly...
reduced during the luteal phase, compared with that shown in group U. Therefore, the intergroup difference in heat loss responses might be greater during the midluteal phase than during the midfollicular phase during exercise. Similarly, there are greater differences in the heat loss responses of untrained and long-term physically trained women during the midluteal phase with passive heating (unpublished observations). In addition, the increase in the sensitivity of the sweating response in the present study was related to an increase in both ASG density and SGO. This observation is in agreement with an earlier study of the secretory activity of the sweat glands of trained women (7).

In summary, our results suggest that heat loss responses in group U during dynamic moderate exercise in a temperate environment in the midluteal phase were inhibited, compared with those of women in the midfollicular phase. This inhibition resulted from lower SR and %LDF values and higher thresholds and lower sensitivities of heat loss responses. By contrast, the menstrual cycle had no remarkable effects in group T, and heat loss responses were improved by long-term physical training. Finally, improvements in heat loss responses were more marked during the midluteal phase than during the midfollicular phase.

ACKNOWLEDGMENTS

We sincerely thank our volunteer subjects for participating in this study. We are also grateful to Dr. M. Hirata and K. Kumabe (Osaka International University) for medical support.

GRANTS

This study was supported by a grant-in-aid for Scientific Research from the Ministry of Education, Culture, Sports, Science, and Technology of Japan (Grant 16500435) and a grant from Kobe University for a research assistant.

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