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Effects of human menstrual cycle on thermoregulatory vasodilation during exercise*

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Summary. To investigate the effects of the menstrual cycle and of exercise intensity on the relationship between finger blood flow (FBF) and esophageal temperature (T_{es}), we studied four women, aged 20—32 years. Subjects exercised at 40% and 70% $\dot{V}_{O_{2\,max}}$ in the semi-supine posture at an ambient temperature of 20°C. Resting T_{es} was higher during the luteal phase than the follicular phase ($P<0.01$). There were no significant differences between the two phases in FBF, oxygen consumption, carbon dioxide production, heart rate or minute ventilation at rest and during exercise, respectively. Each regression line of the FBF-T_{es} relationship consists of two distinct segments of FBF change to T_{es} (slope 1 and 2). FBF increased at a threshold T_{es} for vasodilation ([$T_{es\,0}$]) and the rate of FBF rise became greater at another T_{es} above this threshold ([$T_{es\,0}$']). For both levels of exercise, [$T_{es\,0}$] and [$T_{es\,0}$'] were shifted upward during the luteal phase, but the slopes of the FBF-T_{es} relationship were almost the same in the two phases of the menstrual cycle. Increasing exercise intensity induced a significant decrease in slope 1 of the FBF-T_{es} relationship during the follicular ($P<0.01$) and the luteal phases ($P<0.02$), respectively. These results show that the set-point temperature may be shifted towards a higher level during the luteal phase of the menstrual cycle during exercise and that, as in males, the thermoregulatory vasodilator response is attenuated by increasing exercise-induced vasoconstrictor tone in proportion to exercise intensity during both phases of the menstrual cycle when heat storage is insufficient in women.

Key words: Human menstrual cycle — Leg exercise — Finger blood flow — Thermoregulation — Heat load

Skin blood flow (SBF) increases in proportion to the rise in core temperature (T_c) during exercise. This thermoregulatory response of the cutaneous vessels has been shown to be affected by various factors, such as the intensity of exercise (Hirata et al. 1984a, b), the state of hydration (Nadel 1980), the level of central blood volume (Vroman et al. 1985) and daily rhythms (Wenger et al. 1976). According to Stephenson et al. (1984), the T_c threshold for cutaneous vasodilation during exercise shifts toward higher levels between 1200 and 2000 hours. Besides the shift of T_c threshold, the slope of SBF to T_c tends to increase in the late afternoon, which may mean that the peripheral response to the vasoconstrictor signal might decrease and/or the noradrenergic outflow to the vessels might be reduced during these periods of the day.

In females, the periodic changes in T_c associated with the menstrual phases is well known (Davis and Fugo 1948). Hirashita et al. (1984) also observed periodic changes in T_c threshold for cutaneous vasodilation during the menstrual phases. However, the relation of SBF to T_c during the different phases of the menstrual cycle has not been adequately examined during heat load by exercise. Therefore, the present study attempted to investigate the effects of the different phases of the menstrual cycle and the increases in exercise intensity on the relation of SBF to T_c during heat loads by exercise in women.

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Subjects and methods

Four sedentary healthy adult females with normal menstrual cycles (ranging from 26—34 days) volunteered to serve as subjects (Table 1). The study was carefully explained and informed consent was given by all subjects. Each subject was tested twice in the follicular phase, 6—11 days after the beginning of menstruation, and twice in the luteal phase, 7—9 days after ovulation. The day of ovulation was considered to be that on which the oral basal temperature was lowest in the cycle. The order of testing was randomized so that two subjects had their first test in the follicular phase and the two others were tested first in the luteal phase.

Measurements. Finger blood flow (FBF) was measured by venous occlusion plethysmography using a mercury-in-Silastic strain gauge (Whitney 1953). The strain gauge was wound around the middle finger of the left hand at a tension of 10 g. The venous occlusion cuff was 1.5 cm in width. The cuff was set on the middle finger and inflated to 65 mmHg for 10 s at 20-s intervals. To obtain undistorted plethysmographic records during semi-supine bicycle exercise, the left forearm and hand were supported by a sling. FBF was computed from the slopes of plethysmographic curves, as shown in Fig. 1. Skin temperatures were recorded at seven sites with attached copper-constantan thermocouples (accuracy ±0.01° C), and mean skin temperature ($\bar{T}_{sk}$) was computed once per minute from the recordings according to the following equation:

$$\bar{T}_{sk}=0.07T_1+0.35T_2+0.14T_3+0.05T_4+0.19T_5+0.13T_6+0.07T_7$$

where,
T_1: Forehead, center of forehead
T_2: Trunk, on center of sternum

Table 1. Characteristics of the subjects

Subject	Age (years)	Height (cm)	Weight (kg)	BSA (m^2)	$\dot{V}_{O_{2max}}$ ($l \cdot min^{-1}$)
MS	32	154	46	1.40	2.1
RH	29	163	52	1.55	2.6
YM	20	154	49	1.41	2.2
KY	20	160	45	1.39	2.1
Mean	25.3	157.8	48.0	1.44	2.3
±SE	±3.6	±2.6	±1.8	±0.05	±0.1

BSA, body surface area; $\dot{V}_{O_{2max}}$, maximal oxygen consumption

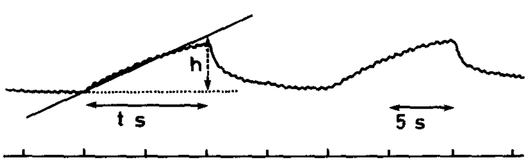

Fig. 1. Representative plethysmographic records during exercise. Time moves from left to right. The *straight lines* on the curve are drawn on the two points between the onset of venous occlusion and the tenth pulse. Slope = $h \cdot t^{-1}$; *h*, change in finger volume for *t* seconds; *t*, a given period of time in seconds

T_3: Arm, lateral lower arm
T_4: Hand, palm of hand on proximal end of 1st metacarpale
T_5: Thigh, lateral mid-thigh
T_6: Calf, lateral mid-calf
T_7: Foot, end of 2 nd toe on side

T_{es} was measured with an esophageal thermistor (YSI, 401) at a depth determined by passing the thermistor through the nose for a distance of one-fourth the subject's height (Wenger et al. 1975). Heart rate (HR) was obtained from the ECG. Oxygen consumption ($\dot{V}_{O_2}$) and carbon dioxide production ($\dot{V}_{CO_2}$) were determined from minute ventilation ($\dot{V}_E$) and the fractions of oxygen (F_{IO_2}, F_{EO_2}) and carbon dioxide in the inspired and expired air (F_{ICO_2}, F_{ECO_2}). $\dot{V}_E$ was recorded with a 100-l twin-type spirometer (Fukuda Irika, Tokyo), expired air being collected through a face mask, and F_{EO_2} and F_{ECO_2} measured by polarograph type O_2- and infrared CO_2-analyzer (1H21A, San-ei Sokki, Toyko), through which a small part of the expired air (200 ml · min^{-1}) was continuously pumped. All tests were conducted in a climatic chamber (TBL-6-S, Tabai MFG Co. Ltd., Osaka) at an ambient temperature (T_a) at 20° ± 1° C and a relative humidity of 50 ± 3%.

Procedures. Before the tests, maximal oxygen consumption ($\dot{V}_{O_{2max}}$) was assessed by no change in $\dot{V}_{O_2}$ despite an increasing exercise intensity, using a bicycle ergometer (Monark) in the upright position. Subsequently, the relationship between work load and $\dot{V}_{O_2}$ was determined during exercise, with the subject in the semi-supine posture and in a reclining chair behind the pedals. The exercise intensity as a percentage of $\dot{V}_{O_{2max}}$ was determined from these data for each subject. The subjects were familiarized with test procedures prior to participating. The subjects reported to the laboratory at 9:00 a.m. after an overnight fast, and sat quietly in the climatic chamber until the test began. They wore only two-piece swimsuits, and were fitted with strain gauges to measure FBF, skin and esophageal temperature sensors, ECG electrodes and a face mask. After the subject had rested in the semi-supine posture for 15 min, the resting data were obtained for the last 5 min of the 20-min rest period. The subject was tested on a bicycle ergometer in the semi-supine posture. Exercise consisted of 30 min at 40% or 70% $\dot{V}_{O_{2max}}$.

Data analysis. The rates of FBF increase to T_{es} between the next two points were calculated for all the points showing the FBF – T_{es} relationship. The amount of increase in FBF in response to the increase in T_{es} between the two succeeding measurements was calculated for all measured points. The rate of the FBF increase to T_{es} was divided into two distinct groups (slope 1 and 2). In the slope 1 group, the rate of FBF increase with increasing T_{es} was small. In the slope 2 group, the rate of FBF increase with increasing T_{es} was larger than that in the slope 1 group. The break point of the overall FBF – T_{es} relationship was determined as the point which was over 4.5 times greater than the average rate of FBF increases in the slope 1 group. Regression analysis for points of FBF increase to T_{es} was calculated for slope 1 and 2 groups, respectively; in one, FBF rose slowly with increasing T_{es} (slope 1, straight line) and in the other the rate of FBF rose rapidly, while T_{es} continued to rise (slope 2, straight line; see Fig. 2). A threshold T_{es} for finger vasodilation ($[T_{es0}]$) was determined by the T_{es} at which FBF was nil on the slope 1 straight line. The rate of FBF rise becomes greater at T_{es} above the threshold T_{es} ($[T_{es0}']$). $[T_{es0}']$ was determined by T_{es} of the cross point between slope 1 and 2 straight lines. The differences between the luteal and the follicular phases, and between the two exercise intensities, were established by paired *t*-test.

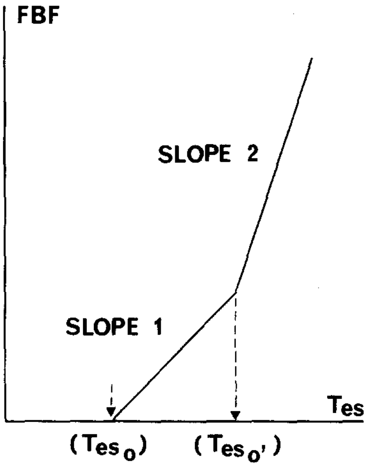

Fig. 2. Schema of data analysis on finger blood flow *(FBF)*-esophageal temperature *(T_{es})* relationship

Results

As shown in Table 2, at rest T_{es} was significantly higher during the luteal phase than during the follicular phase ($P<0.01$). There were no differences in resting $\bar{T}_{sk}$, $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, R, $\dot{V}_E$, HR or FBF between the two phases of the menstrual cycle. During exercise, T_{es}, $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, R, $\dot{V}_E$, HR and FBF increased proportionally to the increase in exercise intensity from 40% to 70% $\dot{V}_{O_{2max}}$ during both phases of the menstrual cycle. There were, however, no significant differences in T_{es}, $\bar{T}_{sk}$, $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, R, $\dot{V}_E$, HR, or FBF during exercise between the two phases of the menstrual cycle.

FBF increased in response to the rise in T_{es} during the follicular and luteal phases during exercise at 40% and 70% $\dot{V}_{O_{2max}}$ (Fig. 3). [T_{es0}] and [T_{es0}'] were significantly shifted upwards in the luteal phase during exercise at both intensities (Fig. 3, Table 3). Although [T_{es0}] at 70% $\dot{V}_{O_{2max}}$ was higher than at 40% $\dot{V}_{O_{2max}}$, there was no significant difference between the two intensities in either phase of the menstrual cycle. [T_{es0}] was significantly higher at 70% $\dot{V}_{O_{2max}}$ than at 40% $\dot{V}_{O_{2max}}$ during both follicular ($P<0.05$) and luteal ($P<0.02$) phases of the menstrual cycle.

As shown in Fig. 3 and Table 4, slopes 1 and 2 were the same during the follicular and the luteal phases at both exercise intensities. However, an increase in exercise intensity from 40% to 70% $\dot{V}_{O_{2max}}$ induced a significant decrease in slope 1 during both phases of the menstrual cycle (Fig. 4, Table 4). The differences in slope 2 between the two intensities were not significant in either phase.

Table 2. Temperature, metabolic, ventilatory and cardiovascular variables at rest and during exercise during the two different phases of the menstrual cycle

	Rest			40% $\dot{V}_{O_{2max}}$			70% $\dot{V}_{O_{2max}}$		
	F	L	Dif.	F	L	Dif.	F	L	Dif.
T_{es}, °C	37.50 ±0.07	37.67 ±0.05	0.17***	37.74[a] ±0.06	37.94[b] ±0.11	0.20	37.94[c] ±0.08	38.12[d] ±0.06	0.18
$\bar{T}_{sk}$, °C	30.02 ±0.14	30.23 ±0.14	0.21	30.96[a] ±0.37	31.39[c] ±0.29	0.43	31.92[a] ±0.33	31.08 ±0.65	−0.84
$\dot{V}_{O_2}$, $l \cdot min^{-1} \cdot m^{-2}$	0.118 ±0.009	0.116 ±0.004	−0.002	0.605[d] ±0.043	0.628[d] ±0.057	0.023	1.086[d] ±0.058	1.085[d] ±0.065	−0.001
$\dot{V}_{CO_2}$, $l \cdot min^{-1} \cdot m^{-2}$	0.090 ±0.007	0.089 ±0.003	−0.001	0.476[d] ±0.035	0.492[d] ±0.047	0.016	0.920[d] ±0.039	0.899[d] ±0.038	−0.021
R	0.766 ±0.008	0.762 ±0.007	−0.004	0.788[a] ±0.018	0.783[a] ±0.002	−0.005	0.849[b] ±0.011	0.827[b] ±0.013	−0.022
$\dot{V}_E$, $l \cdot min^{-1} \cdot m^{-2}$	3.6 ±0.4	3.2 ±0.2	−0.4	13.5[d] ±1.1	14.8[d] ±1.4	1.3	26.6[d] ±1.6	28.7[d] ±0.8	2.1
HR, bpm	66.6 ±1.1	65.9 ±1.3	−0.7	120.8[d] ±3.2	117.3[d] ±2.3	−3.5	157.7[d] ±2.9	155.5[d] ±5.7	−2.2
FBF, $ml \cdot 100\ ml^{-1} \cdot min^{-1}$	1.8 ±0.4	1.6 ±0.4	−0.2	40.3[a] ±9.7	48.3[a] ±11.2	8.0	74.5[d] ±3.1	84.8[b] ±18.7	10.3

Values are means ±SE. Statistically significant from the corresponding rest values: [a] $P<0.05$; [b] $P<0.02$; [c] $P<0.01$; [d] $P<0.001$. *** $P<0.01$ for comparison of values for the follicular and the luteal phases

Dif., mean difference between the two phases; F, follicular phase; L, luteal phase; T_{es}, esophageal temperature; $\bar{T}_{sk}$, mean skin temperature; $\dot{V}_{O_2}$, oxygen consumption; $\dot{V}_{CO_2}$, carbon dioxide production; R, respiratory exchange ratio expressed as $\dot{V}_{CO_2}/\dot{V}_{O_2}$; $\dot{V}_E$, minute ventilation; HR, heart rate; FBF, finger blood flow

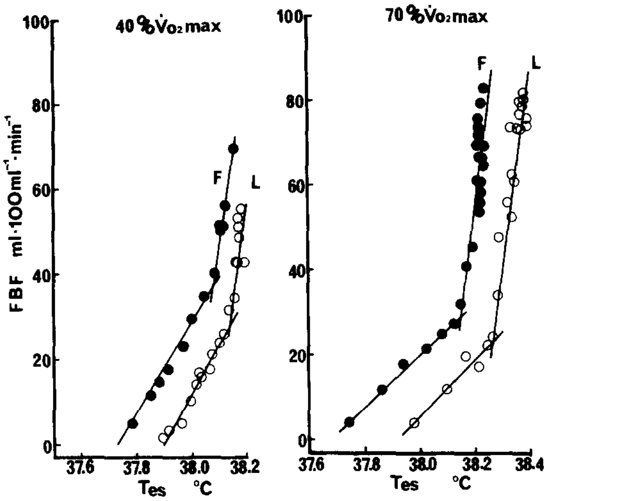

Fig. 3. Effects of the follicular and luteal phases during the menstrual cycle on the individual relationship between finger blood flow *(FBF)* and esophageal temperature *(T_{es})* at 40% *(left)* and 70% $\dot{V}_{O_{2max}}$ *(right)* in subject MS

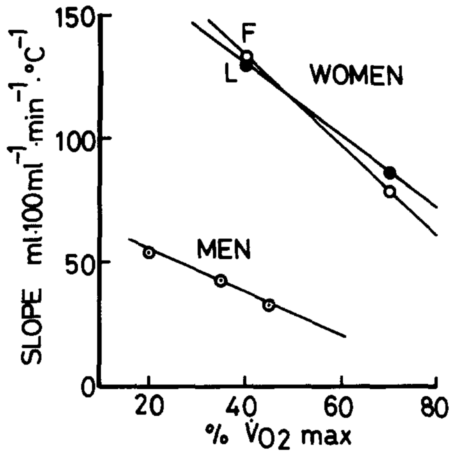

Fig. 4. Comparison of mean slope 1 for follicular *(F)* and luteal *(L)* phases of the menstrual cycle in four women (this study) and the men in a previous study (Hirata et al. 1984b) as a function of % $\dot{V}_{O_{2max}}$ at an ambient temperature of 20° C

Discussion

The resting T_{es} was significantly higher (+0.17° C) during the luteal phase than during the follicular phase. The difference in T_{es} between two phases was similar during exercise, but was not statistically significant (Table 2). These results are in agreement with those reported by Horvath and Drinkwater (1982). There were no differences in $\bar{T}_{sk}$, HR, $\dot{V}_E$, $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$ or R between the two phases at rest and during exercise. The studies of some investigators (Jurkowski et al. 1981; Stephenson et al. 1982) have shown no difference in these parameters between the two phases at rest and during exercise. Their results are confirmed by our data. Horvath and Drinkwater (1982) have reported that forearm blood flow in the recovery period of exercise was higher during the flow

Table 3. Changes in threshold esophageal temperature for vasodilation [T_{es}o] and for outward release of exercise-intensity-related factor [T_{es}o'] in the follicular and luteal phases during exercise at 40% and 70% $\dot{V}_{O_{2max}}$

	Subject	40% $\dot{V}_{O_{2max}}$			70% $\dot{V}_{O_{2max}}$		
		F	L	Dif.	F	L	Dif.
	MS	37.73	37.90	+0.17	37.64	37.95	+0.31
	RH	37.29	37.38	+0.09	37.57	37.85	+0.28
[T_{es}o]	YM	37.12	37.43	+0.31	37.45	37.52	+0.07
°C	KY	37.79	37.88	+0.09	37.78	37.98	+0.20
	Mean	37.48	37.65	+0.17*	37.61	37.84	+0.22*
	±SE	±0.16	±0.14	±0.05	±0.07	±0.11	±0.05
	MS	38.04	38.08	+0.04	38.10	38.21	+0.11
	RH	37.71	37.84	+0.13	37.99	38.14	+0.15
[T_{es}o']	YM	37.60	37.98	+0.38	37.89	38.14	+0.25
°C	KY	37.88	37.94	+0.06	38.01	38.15	+0.14
	Mean	37.81	37.96	+0.15	38.00[a]	38.16[b]	+0.16
	±SE	±0.10	±0.05	±0.08	±0.04	±0.02	±0.03

Statistically significant from the corresponding values during exercise at 40% $\dot{V}_{O_{2max}}$: [a] $P<0.05$; [b] $P<0.02$.
* $P<0.05$ and ** $P<0.02$ for comparison of values for the follicular and the luteal phases.
Abbreviations are the same as for Table 2

Table 4. Slopes of the regression lines of the finger blood flow (FBF)-esophageal temperature (T_{es}) relationship in the follicular and luteal phases during exercise at 40% and 70% $\dot{V}_{O_{2max}}$

	Subject	40% $\dot{V}_{O_{2max}}$			70% $\dot{V}_{O_{2max}}$		
		F	L	Dif.	F	L	Dif.
Slope 1	MS	106.3	116.8	+ 10.5	52.5	66.9	+ 14.4
	RH	168.4	156.0	− 12.4	103.7	114.3	+ 10.6
	YM	133.3	141.6	+ 8.3	78.1	85.2	+ 7.1
	KY	124.5	109.0	− 16.4	86.1	82.3	− 3.8
	Mean	133.4	130.9	− 2.5	80.1[d]	87.2[b]	+ 7.1
	±SE	±13.0	± 10.9	± 6.9	±10.6	± 9.9	± 3.9
Slope 2	MS	288.6	256.2	− 32.4	347.2	364.3	+ 17.1
	RH	296.4	655.3	+358.9	476.7	385.3	− 91.4
	YM	191.6	208.2	+ 16.6	197.2	201.4	+ 4.2
	KY	450.0	182.2	−267.9	403.8	205.1	−198.7
	Mean	306.7	325.5	+ 18.8	356.2	289.0	− 67.2
	±SE	±53.4	±111.0	±129.3	±59.3	±49.7	± 50.1

Slope: $ml \cdot 100\ ml^{-1} \cdot min^{-1} \cdot {}^{\circ}C^{-1}$. Statistically significant from the corresponding values during exercise at 40% $\dot{V}_{O_{2max}}$: [b] $P<0.02$ and [d] $P<0.01$.
Abbreviations are the same as for Table 2

phase of the menstrual cycle than during the luteal phase. In the present study, there was a tendency for higher FBF during the luteal phase than during the follicular phase, but the difference was not significant.

FBF-T_{es} relationship. In the present study, we obtained a similar FBF-T_{es} relationship to that in our previous study in men (Hirata et al. 1984a, b). There were two distinct FBF-T_{es} slopes during both phases of the menstrual cycle during exercise at both intensities. Change in FBF during exercise is the net result of the competition between the thermoregulatory vasodilator and the exercise-induced vasoconstrictor responses. The increase in heat load during exercise attenuates the exercise-induced vasoconstrictor response (Johnson and Park 1982). Therefore, exercise-induced vasoconstrictor tone is relatively stronger in slope 1 than in slope 2, when heat storage is smaller, as shown by a lower T_{es} during exercise, whereas the thermoregulatory vasodilator tone becomes relatively stronger in slope 2 at higher T_{es} above [$T_{es\,0}$']. There are many arteriovenous anastomoses (AVAs) in particular regions of the human skin, such as fingers and toe tips, eyelids, ear lobes and lips (Sherman 1963). It is said that AVAs play an important role in thermoregulation, and blood flow through cutaneous AVAs is controlled by thermoregulatory reflexes, mainly due to changes in deep body temperature (Hales et al. 1978). As the patency of AVAs provides a high blood flow, the FBF-T_{es} relationship in the present study might be shown by the two distinct straight lines instead of the smooth curve.

Many investigators have reported that the relationship between SBF and T_{es} is greatly affected by various factors such as day-night cycle (Stephenson et al. 1984; Wenger et al. 1976), fever (Nadel 1977), the state of hydration and osmolarity (Nadel 1980), posture (Johnson et al. 1974), heat acclimation (Roberts et al. 1977) and exercise intensity (Hirata et al. 1984a, b). An upward shift of the threshold T_{es} for forearm vasodilation has also been obtained in febrile conditions, dehydration and hyperosmolar conditions and change in posture from supine to upright without a change in the slope of the SBF-T_{es} relationship. The results of these investigations coincide with those for the menstrual cycle obtained in the present study. As shown in Fig. 3, an upward shift of [$T_{es\,0}$] was observed during the luteal phase of the menstrual cycle at both exercise intensities ($P>0.05$). [$T_{es\,0}$'] also shifted upwards during the luteal phase. However, there were no differences in the slopes of the FBF-T_{es} relationship (sensitivity) between the two phases of the menstrual cycle during exercise at 40% and 70% $\dot{V}_{O_{2max}}$. There was no evidence for a shift of sympathetic tone in HR or $\bar{T}_{sk}$ (Table 2). Therefore, there may be no difference in noradrenergic outflow to the cutaneous vessels between the two phases of the menstrual cycle during exercise. The upward shifts of [$T_{es}o$] and [$T_{es}o$'] during the luteal phase can be explained by the shift of the setpoint to a higher level (Cunningham and Cabanac 1971), and would be concerned with the changes in central blood or plasma volume (Johnson et al. 1974; Nadel 1980; Vroman et al. 1985).

Effects of exercise intensity on FBF-T_{es} relationship

In this study, increasing exercise intensity from 40% to 70% $\dot{V}_{O_{2max}}$ induced a significant decrease in slope 1 during both phases of the menstrual cycle. The average slopes of the FBF-T_{es} relationship were 133.4 and 80.1 at 40% and 70% $\dot{V}_{O_{2max}}$ during the follicular phase, and 130.9 and 87.2 $ml \cdot 100\ ml^{-1} \cdot min^{-1} \cdot °C^{-1}$ at 40% and 70% $\dot{V}_{O_{2max}}$ during the luteal phase, respectively (Fig. 4). The present results in women coincide with our previous results in men (Hirata et al. 1984a, b). At a T_a of 15°–25° C, slope 1 of FBF-T_{es} relationship significantly decreased with increasing exercise intensity from 20% to 45% $\dot{V}_{O_{2max}}$. At a T_a of 20° C, the average slopes of the FBF-T_{es} relationship were 54.5, 43.8 and 33.1 $ml \cdot 100\ ml^{-1} \cdot min^{-1} \cdot °C^{-1}$ at 20%, 35% and 45% $\dot{V}_{O_{2max}}$, respectively (Fig. 4). The slopes of the FBF-T_{es} relationship were about 3.5 times steeper in women than those in men at 40% $\dot{V}_{O_{2max}}$. These results may have suggested either lower sympathetic tone or greater inhibition of noradrenergic outflow with increasing T_{es} in women than in men. Roberts et al. (1977) have shown that the slope of the SBF-T_{es} relationship becomes steeper following heat acclimation. Therefore, a higher blood flow sensitivity to T_{es} in women would be concerned with the degree of heat acclimation. To explain the great sex differences in slope 1 at a given exercise intensity, further investigations will be necessary. Despite the higher blood flow sensitivity to T_{es} in women, [$T_{es}o$] and [$T_{es}o$'] were higher in women than in men. These results may support the conclusion that women have a higher core temperature than men for a given heat load (Brouha et al. 1960; Dill et al. 1973).

The present study and our previous studies (Hirata et al. 1984a, b), have shown that for the smaller heat storages at T_{es} below [$T_{es}o$'] induced by exercise in the rather cool environment at T_a from 15 to 25 °C, exercise-induced vasoconstrictor tone in proportion to exercise intensity is always sufficiently larger than thermal vasodilator tone. However, at a T_a of 30° C and for greater heat storages at T_{es} above [$T_{es}o$'] induced by exercise, the thermal vasodilator tone would always be sufficient to mask the existence of an intensity-related exercise-induced vasoconstrictor tone. Therefore, we could not find any intensity-related change in slope 2 of the FBF-T_{es} relationship (Fig. 3, Table 4).

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References

Brouha L, Smith PE, De Lanne R, Maxfield ME (1960) Physiological reactions of men and women during muscular activity and recovery in various environments. J Appl Physiol 16:133–140

Cunningham DJ, Cabanac M (1971) Evidence from behavioral thermoregulatory responses of a shift in setpoint temperature related to the menstrual cycle. J Physiol [Paris] 63:236–238

Davis ME, Fugo NW (1948) The cause of physiologic basal temperature changes in women. J Clin Endocrinol 8:550–563

Dill CB, Yousef K, Nelson JD (1973) Response of men and women to two-hour walks in desert heat. J Appl Physiol 35:231–235

Hales JRS, Fawcett AA, Bennett JW, Needham AD (1978) Thermal control of blood flow through capillaries and arteriovenous anastomoses in skin of sheep. Pflügers Arch 378:55–63

Hirashita M, Hirai A, Takahata T, Nunomura T, Nagasaka T (1984) Shift of setpoint temperature to increase non-evaporative heat loss related to the menstrual cycle. J Aerospace Environ Med 21:29–34

Hirata K, Nagasaka T, Hirai A, Hirashita M, Takahata T (1984a) Suppression of finger vasodilator response during exercise in proportion to its intensity. In: Hales JRS (ed) Thermal physiology. Raven Press, New York, pp 381–384

Hirata K, Nagasaka T, Hirai A, Hirashita M, Takahata T (1984b) Cutaneous vascular tone during heat load modified by exercise intensity. J Therm Biol 9:117–120

Horvath SM, Drinkwater BL (1982) Thermoregulation and the menstrual cycle. Aviat Space Environ Med 53:790–794

Johnson JM, Park MK (1982) Effect of heat stress on cutaneous vascular responses to the initiation of exercise. J Appl Physiol 53:744–749

Johnson JM, Rowell LB, Brengelmann GL (1974) Modification of the skin blood flow-body temperature relationship by upright exercise. J Appl Physiol 37:880–886

Jurkowski JE, Jones NL, Walker WC, Younglai EV, Sutton JR (1978) Ovarian hormonal responses to exercise. J Appl Physiol 44:109–114

Jurkowski JEH, Jones NL, Toews CJ, Sutton JR (1981) Effects of menstrual cycle on blood lactate, O_2 delivery, and performance during exercise. J Appl Physiol 51:1493–1499

Nadel ER (1977) A brief overview. In: Nadel ER (ed) Problems with temperature regulation during exercise. Academic Press, New York, pp 1–10

Nadel ER (1980) Circulatory and thermal regulations during exercise. Fed Proc 39:1491–1497

Roberts MF, Wenger CB, Stolwijk JAJ, Nadel ER (1977) Skin blood flow and sweating changes following exercise training and heat acclimation. J Appl Physiol 43:133–137

Sherman JL (1963) Normal arteriovenous anastomoses. Medicine [Baltimore] 42:247–267

Stephenson LA, Kolka MA, Wilkerson JE (1982) Metabolic and thermoregulatory responses to exercise during the human menstrual cycle. Med Sci Sports Exerc 14:270–275

Stephenson LA, Wenger CB, O'Donovan BH, Nadel ER (1984) Circadian rhythm in sweating and cutaneous blood flow. Am J Physiol 246:R321–R324

Vroman NB, Beckett WS, Permutt S, Fortney S (1985) Effect of positive-pressure breathing on cardiovascular and thermoregulatory responses to exercise. J Appl Physiol 58:876–881

Wenger CB, Roberts MF, Stolwijk JAJ, Nadel ER (1975) Forearm blood flow during body temperature transients produced by leg exercise. J Appl Physiol 38:58–63

Wenger CB, Roberts MF, Stolwijk JAJ, Nadel ER (1976) Nocturnal lowering of threshold for sweating and vasodilation. J Appl Physiol 41:15–19

Whitney RJ (1953) The measurement of volume changes in human limbs. J Physiol 121:1–127

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