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Higher Sweating Rate and Skin Blood Flow during the Luteal Phase of the Menstrual Cycle

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Evaporation by sweating is the most effective way to remove heat from the body. Sweat rates increase under both local and whole-body heat stress. Men and women differ in how they respond to heat, because sexual steroids alter resting body core temperature and the threshold for sweating and skin blood flow (SBF) during heating. The purpose of the present study was to compare local sweat rates and cutaneous vasodilatation during heat exposure in women with a regular menstrual cycle. The cutaneous vasodilatation was judged by measuring the SBF. Eight female and nine male subjects participated in this study, and their age range was 24-29 years. Female subjects were tested twice throughout one full menstrual cycle: once during the middle follicular phases and once during the luteal phase. Subjects remained in a temperature-regulated room at 41°C and 21% of relative humidity for 40 minutes. Sweat rate was recorded from the forehead, forearm, and thigh, and skin temperature and SBF were measured on the thigh and forehead. We found that the sweating rate and SBF were greater in the luteal phase compared to follicular phase ($p < 0.05$). Since both SBF and sweating were controlled by the sympathetic nerve system, the sympathetic outflow was greater during whole body heat exposure in the luteal phase. In contrast, for men, there was no significant difference in sweating and SBF over the same calendar period ($p > 0.05$). We propose the enhanced sympathetic activity in the luteal phase with a regular menstrual cycle.

Keywords: cutaneous vasodilatation; estrogen; menstrual cycle; progesterone; sweat rate
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Introduction

Evaporation by sweating is the most effective way to remove heat from the body (Petrofsky et al. 2005). Sweat rates increase under both local and whole-body heat stress. This is reflex in nature to maintain body core temperature (Shibasaki et al. 2006; Wingo et al. 2010). But, women's heat response from whole-body heat stress or during exercise is different than that of men (Avellini et al. 1980; Gagnon and Kenny 2012). It is well documented that body core temperature fluctuates during the menstrual cycle in women due to female reproductive hormones, especially, progesterone. Progesterone concentration peaks during the luteal phase whereas it decreases during the follicular phase (Petrofsky et al. 1976, 2005; Simao et al. 2012). The concentration of progesterone is correlated with elevated core temperature and also the threshold for sweating and skin blood flow (SBF) during exercise (Stephenson and Kolka 1985; Charkoudian and Johnson 2000; Inoue et al. 2005). Inoue and colleagues have shown that mean body temperature and SBF are greater during the luteal phase where progesterone is higher compared to the follicular phase (Inoue et al. 2005; Kuwahara et al. 2005). Oral contraceptive pills (OCP) are active in suppressing pituitary production of follicle-stimulating hormone and luteinizing hormone and preventing ovulation from occurring (Kenny et al. 2008). Combined estrogen and progesterone as synthetic steroids are the main components of OCP and this exogenous source of synthetic forms of the hormones, prevents ovulation by maintaining consistent hormone levels (Krishnan and Kiley 2010). The effect of progesterone and estrogen on body core temperature is well established. It is interesting that many for the changes in muscular blood flow and endurance are not seen in women on oral contraceptives, showing the impact of the hormones in non OCP users (Petrofsky et al. 1976). Therefore, the effect of menstrual cycle on sweat rate and cutaneous vasodilatation is probably a complex interaction between progesterone and estrogen. Thus, in the present study, we compared local sweat rate and cutaneous blood flow from whole-body heat stress between

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women with a regular menstrual cycle and men.

Methods

Subjects

Eighteen young healthy adults between the ages of 24 and 29 years old participated in this study. Subjects were divided into two groups: female subjects with a regular menstrual cycle and male group. All subjects were physically inactive with a body mass index (BMI) between 15 and 30. Subjects had no history of pregnancy, cardiovascular disease, hepatic disease, diabetes, and were not taking any medication would affect sex hormones. All methods and procedures were approved by the Institutional Review Board of Loma Linda University, and all subjects signed a statement of informed consent before participating the study.

Procedures

Female subjects were tested twice throughout one full menstrual cycle; once during the middle follicular phases (6 to 9 days after the onset of menstruation) and once during the luteal phase (21 to 24 days after the onset of menstruation). Since these phases do not occur in the male group, testing occurred at match days. Female subjects were asked to report the days of their cycle at the beginning of the study. Since body core temperature fluctuates during the day, the various tests performed at the same time period each day (between 9 am to 11 am).

On the first day, before beginning the experiment, height, weight, BMI, skin thickness, and fat thickness were measured. On each day, after the subjects arrived at laboratory, they rested comfortably in a regulated temperature room at 25°C for 20 minutes to stabilize their body temperature in a neutral environment. Each subject wore short sleeve T-shirts and shorts during the tests. Subjects remained in a temperature regulated room at 41°C and 21% of relative humidity (RH) for 40 minutes. Sweat rate at 3 different areas (forehead, forearm, and thigh), skin temperature, and SBF were measured throughout the test. Subjects were allowed to drink water during heat stress.

Measurements

Local sweat rate: Three different local sweat rates were measured with a Q-Sweat measuring system (WR Medical Electronics, Stillwater, MN). The system provided a constant source of air pressure being applied through sweat capsules mounted on the skin. The constant source of air to each capsule was first dried in Dri-rite and by applying air at a constant flow rate; outgoing air from the capsules could be assessed for humidity. By knowing the temperature of the air, the flow rate and humidity in the capsule, sweat rate were calculated. Three sweat capsules were used, on the forehead, calf, and on the forearm.

Skin temperature: Skin temperature was measured with a thermistor (SKT RX 202A) manufactured by Bio Pac systems (Bio Pac Inc., Goleta, CA). The SKT 100 thermistor amplifier (Bio Pac Inc., Goleta, CA) sensed the thermistor output. The output, which was a voltage between 0 and 10 volts, was sampled with an analog-to-digital converter at a frequency of a 1,000 samples per second with a resolution of 24 bits using a Bio Pac MP150 analog-to-digital converter. The converted data was then stored on a desktop computer using Acknowledge 4.1 software for later analysis. Data were analyzed over a 5-second period for mean temperature. The temperature was calibrated at the beginning of each day by placing the thermistors in a controlled temperature water bath calibrated against a standard thermometer.

Skin blood flow (SBF): The SBF was measured with a Moor Laser Doppler flow meter (VMS LDF20, Oxford, England). The system uses a red laser beam (632.8 nm) to measure SBF using the Doppler Effect. After warming the laser for 15 to 30 minutes prior to use, the laser was applied to the skin through a VP12B fiber optic probe placed above the forearm. The Moor Laser Doppler flow unit measured SBF through most of the dermal layer of the skin. The SBF was then calculated in a unit called Flux, based on the red cell concentration and red cell velocity with a stated accuracy of ± 10%.

Statistical analysis

Data were summarized as means and standard deviations. Baseline characteristics and sweat rates of two groups was compared using an independent *t*-test. Skin temperature and SBF were compared by a mixed factorial analysis of variance (ANOVA) with repeated measures. The level of significance was set at $\alpha = 0.05$.

Results

Nine subjects were enrolled in each group. However, one subject from the female group was excluded because the subject started taking OCP during the study. The subject's menstrual phase was determined by their self-reporting. General characteristics of 17 subjects are shown in Table 1.

Skin temperature

The skin temperature measured over the 40-minute period is shown in Fig. 1 in the female subjects in the follicular and luteal phases of the menstrual cycle. As shown in Fig. 1, the skin temperature was higher by about 2.5°C in the luteal than the follicular phase ($p < 0.01$). For the males, the skin temperature remained at 32.1°C throughout the exposure to heat.

Sweat rates

The sweat rates in the women during the two phases of the menstrual cycle are illustrated in Figs. 2, 3 and 4 for the

Table 1. General characteristics of 8 female and 9 male subjects.

		Age (years)	Height (cm)	Weight (kg)	BMI
women	Mean	25.00	161.47	56.81	21.78
	s.d.	1.85	6.34	7.99	2.73
men	Mean	26.90	176.63	82.69	26.52
	s.d.	2.08	5.80	10.92	3.34

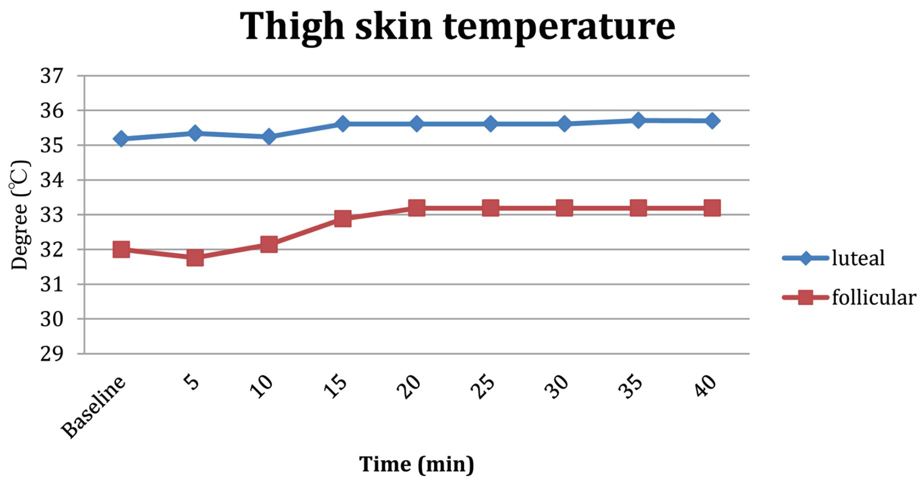

Fig. 1. Thigh skin temperature in the women in the two phases of the menstrual cycle. Each point is the mean of 8 female subjects.

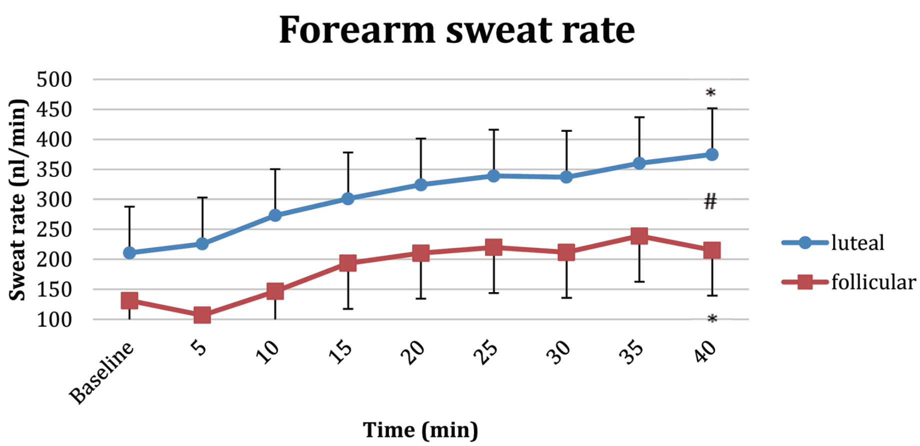

Fig. 2. Forearm sweat rate in the women in the two phases of the menstrual cycle. Each point is the mean of 8 female subjects ± the standard deviation.
*Significant increases from baseline.
#Significant difference between luteal and follicular phase.

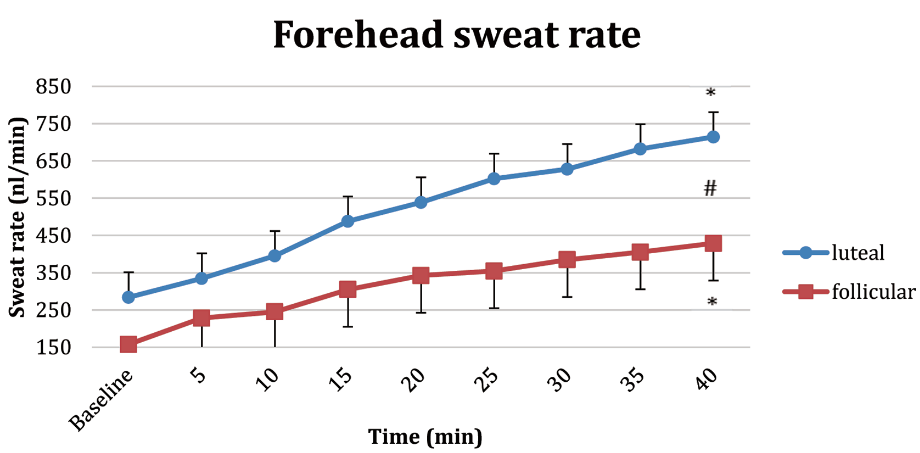

Fig. 3. Forehead sweat rate in the women in the two phases of the menstrual cycle. Each point is the mean of 8 female subjects ± the standard deviation.
*Significant increases from baseline.
#Significant difference between luteal and follicular phase.

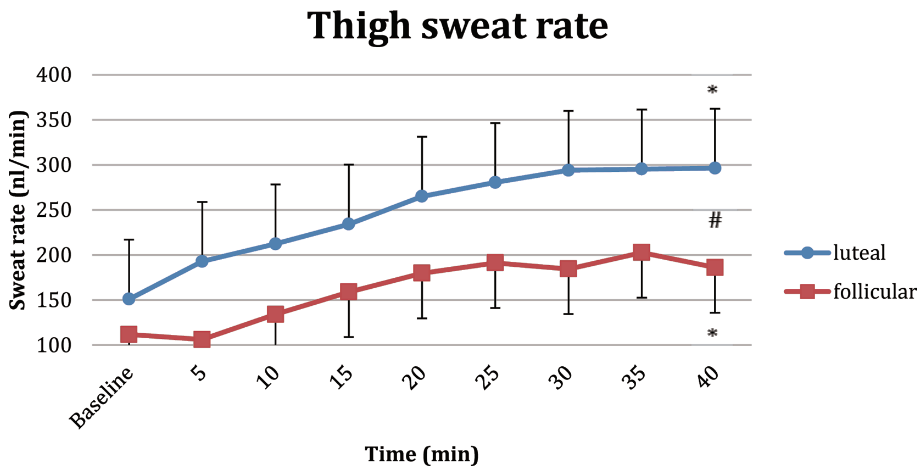

Fig. 4. Thigh sweat rate in the women in the two phases of the menstrual cycle. Each point is the mean of 8 female subjects ± the standard deviation.
*Significant increases from baseline.
#Significant difference between luteal and follicular phase.

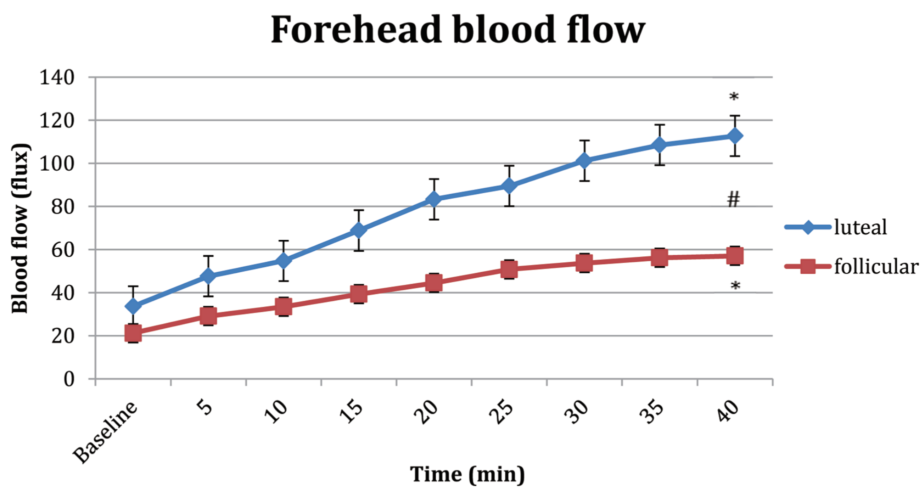

Fig. 5. Forehead skin blood flow in the women in the two phases of the menstrual cycle. Each point is the mean of 8 female subjects ± the standard deviation.
*Significant increases from baseline.
#Significant difference between luteal and follicular phase.

forearm, forehead and thigh respectively. As shown in these figures, the sweat rate rose steadily throughout the exposure period. This increase on each area in sweat was significant ($p < 0.01$) comparing the initial sweat rate to the sweat rate after 40 minutes of heat exposure. In all 3 cases, the sweat rate in the luteal phase was significantly greater than the follicular phase ($p < 0.05$).

Skin Blood Flow (SBF)

The blood flow in the skin for the forehead and thigh is illustrated in Figs. 5 and 6 respectively for the 8 women. As illustrated here, the blood flow increased for both phases of the menstrual cycle at both sites. The increase in SBF was significant over the 40 minutes for both phases of the menstrual cycle ($p < 0.01$). While resting SBF at either site was not statistically different ($p > 0.05$), by 15 minutes of exposure the SBF was significantly higher in the women during the luteal phase of the menstrual cycle ($p < 0.05$).

Male subjects

For the male subjects, the sweat and SBF data was significantly higher than that which was found for the women in either phase of their menstrual cycles. A typical example is shown in Fig. 7. The forehead sweat data is shown in this figure. The sweat rate at each area in the men was significantly greater than that seen in the women ($p < 0.01$). While there was a significant increase in SBF and sweat over exposure, there were no significant differences in these measures between the two measurements ($p > 0.05$). The SBF followed a similar response with SBF higher in the men than the women throughout the heat exposure.

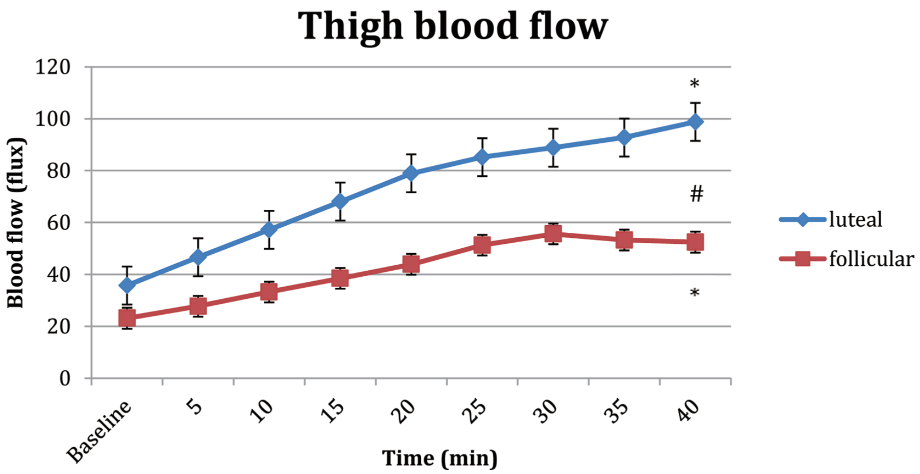

Fig. 6. Thigh skin blood flow in the women in the two phases of the menstrual cycle. Each point is the mean of 8 female subjects ± the standard deviation.
*Significant increases from baseline.
#Significant difference between luteal and follicular phase.

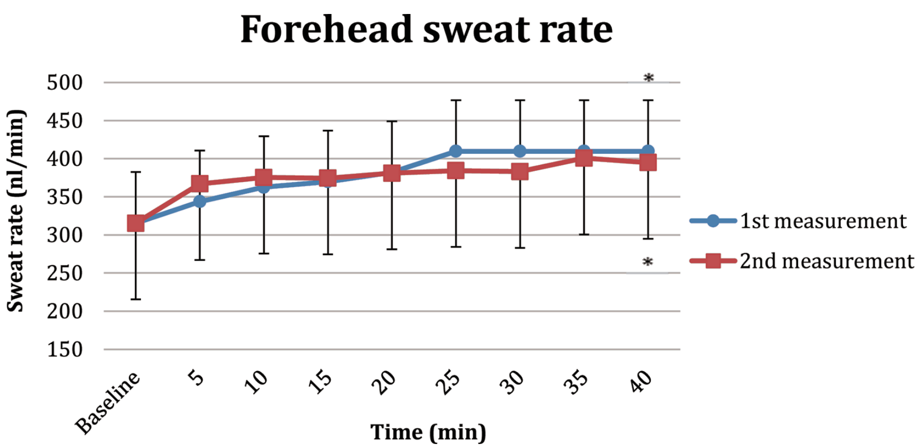

Fig. 7. Forehead sweat rate in the men in the two different measurements. Each point is the mean of 9 male subjects ± the standard deviation.
*Significant increases from baseline.

Discussion

Estrogen and progesterone in women have well documented effects on the body. One of the most apparent effects is on body temperature and the thermoregulatory system (Charkoudian and Johnson 2000; Charkoudian 2001, 2003). Beta estrogen receptors are found throughout the body including the central nervous system (Paterni et al. 2014). These receptors control a variety of functions including tissue synthesis, tissue blood flow and body temperature (Petrofsky et al. 1976). In this respect, estrogen and progesterone have an antagonistic role where the effects of estrogen on beta receptors are opposed by progesterone (Silva et al. 2000; Stachenfeld et al. 2000).

In the present investigation, data supported the concept that there are not just changes in body temperature during the second half of the menstrual cycle, but changes in vasomotor and sudomotor activity as well. Skin temperature was higher, sweating greater and skin circulation greater in the luteal phase of the menstrual cycle. The fact that men who were measured at the same time did not have a change sweat rates or blood flow when comparing the two measuring points separated by 2 weeks supports the concept that this is not environmental but physiological. Interestingly, the sweat rates and cutaneous vasodilation was greater in men than women. But women have a smaller mass and greater surface are to sweat from and therefore, potentially, sweat rates and SBF per meter skin surface area may not be very different.

It has been reported that sweat rates and cutaneous vasodilatation increases in the luteal phase of the menstrual cycle (Kolka and Stephenson 1997; Dzeletovic et al. 2012), but such a fact seems counterintuitive. During the luteal phase when progesterone is high, the body's thermostat is reset to a higher temperature (Stephenson and Kolka 1999). This is accomplished by reducing skin vasodilation so that metabolism warms the body. But by the same mechanism, the higher body temperature seems to make the body more sensitive to heat stress and increases autonomic activity to the thermoregulatory system. Recent studies do not show an increase in sympathetic activity during the luteal phase of the menstrual cycle (Tenan et al. 2014). In fact, analysis of heart rate variability shows that heart rate increases during the luteal phase compared to the follicular phase due to a withdrawal of parasympathetic tone (Tenan et al. 2014). No such change was seen in sympathetic tone. Thus the general increase in SBF and sweat rates in the heat must be centered in hypothalamic control and not due to a general increase in sympathetic activity; the parasympathetic system exerts no influence on sweat glands and SBF. While many studies have examined either SBF or sweating during the menstrual cycle, there is some controversy on the findings. Some report little to no change in SBF and others do with the menstrual cycle (Stephenson and Kolka 1999; Stachenfeld et al. 2000; Dzeletovic et al. 2012). But SBF was measured in the whole limb or on the skin. Sometimes it was measured together with sweat rates during local heat and sometimes exercise (Freedman and Subramanian 2005; Garcia et al. 2006; Janse et al. 2012). Here, unlike most studies, the subjects were kept in a temperature-controlled room at the same time of the day and same phase of the menstrual cycle. In this respect this study removes some of the variables that have plagued previous studies. Further investigation is warranted.

Conflict of Interest

The authors declare no conflict of interest.

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