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The Effect of Different Phases of The Menstrual Cycle on Some Physiological Indicators (Heart Rate, Blood Pressure, Maximal Oxygen Consumption and Anaerobic Capacity) In Female Athletes

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ARTICLE INFO	ABSTRACT
<p>Article History: Received 4 July 2019 Received in revised form 20 September 2019 Accepted 15 December 2019 Available online 17 December 2019</p>	<p>The aim of the present study was to investigate the effect of different phases of the menstrual cycle on physiological indicators (heart rate, blood pressure, VO₂max and anaerobic capacity) in female athletes. 15 female athletes (mean age 21.73±1.49 years, height 1.61±0.04 m, weight 58.03±5.99 kg) with at least three years of athletic experience and no history of taking hormonal and sexual drugs for six months participated in this study because their monthly cycle was normally 25-35 days. To accurately determine the different phases of the monthly cycle (early follicular phase, late follicular phase, and mid-luteal phase), estrogen and progesterone measurements were used by the blood serum method. To minimize the effects of learning, the subjects were randomly divided into three groups, and each group started the test from a different phase than the other groups. Resting heart rate on awakening and blood pressure after half an hour of rest before blood sampling and lying down were measured. Riming-Astrand and RAST submaximal tests were also used to estimate VO₂max and anaerobic power. Repeated measures analysis of variance and Bonferroni's post hoc test ($P \geq 0.05$) were used to analyze the research results. The results showed that Resting heart rate increased significantly during the mid-luteal phase compared to the other two phases. At the end of the follicular phase, resting systolic blood pressure and VO₂max showed a significant increase. Also, maximum anaerobic power and fatigue index were associated with a significant decrease in the mid-luteal phase, while no significant difference was observed in resting diastolic blood pressure, minimum power and average power. The results obtained confirm the influence of the different phases of the menstrual cycle on the physiological indicators of female athletes; therefore, when measuring the physiological indicators of athletes, the effect of the different phases of the menstrual cycle should also be considered.</p>
<p>Keywords: Monthly Period, Physiological Indicators, Female Athletes, VO₂max, Anaerobic Power, Heart Rate, Blood Pressure</p>	

1. INTRODUCTION

With the increasing growth and development of sports knowledge, the phenomenon of women's sports and their participation in recreational and competitive activities has received more and more attention from scientific centers.

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Meanwhile, the study of women's specific issues such as menstruation, pregnancy, and the structural and physiological differences of women and their relationship with sports performance are proposed to be studied. One of the important and controversial issues in women's sports is the interaction between physical activity and menstruation [1]. The menstrual cycle begins with the bleeding phase, followed by the follicular phase, and ends with the luteal phase. A low concentration of estrogen and progesterone hormones indicates the bleeding phase, an increase in estrogen and a low amount of progesterone is a sign of the follicular phase, and the presence of high amounts of estrogen and progesterone is a sign of the luteal phase [2, 3]. The fluctuation of estrogen and progesterone hormones during the monthly period affects the physiology of women's body [3, 4, 5], especially in the early follicular, late follicular and mid-luteal phases of the monthly period, three different hormonal profiles have been shown to occur during the monthly period [3]. Estrogen has an effect on the cardiovascular, bone, and brain systems, and progesterone is also an important regulator of these systems. It is responsible for body temperature and respiration, and basal metabolism is affected by both hormones [1, 6].

For this reason, a person's physical capacity is likely to be different at each of the above stages, which may lead to improvement or deterioration in exercise performance at different times during the menstrual cycle [4, 5]. On the other hand, one of the most important and decisive factors of athletic performance of interest to coaches and athletes are physiological indicators, including aerobic capacity (maximum oxygen consumption) and anaerobic capacity. Maximum oxygen consumption (VO₂max), as a predictor of an athlete's potential and capacity, measures and evaluates the level of preparation [7]. The higher the athlete's VO₂max, or in other words, the amount of oxygen that the cardiovascular system can transfer to the muscles and the blood supply to the large mass of muscles involved in the activity increases, the greater the person's ability to perform the activities [8]. Strength is also an important factor in physical fitness programs and plays an important role in sports preparation programs. Anaerobic power is the maximum ability of a person to use two systems of phosphagen and lactic acid to produce energy in a unit of time [9]. There are different findings regarding the possible influence of the menstrual cycle on the athletic performance of female athletes, that in some cases the athletic performance of women during the menstrual cycle is reduced, and that in a large number of female athletes the athletic performance is unchanged or accompanied by positive changes [3, 5]. According to research, hormonal fluctuations that occur during the monthly period lead to changes in plasma volume [10], blood hemoglobin accumulation [11], blood lactate accumulation, fat metabolism, body weight [3], body temperature and respiratory responses [12].

Food availability, blood flow and respiration are among the most important physiological factors affecting VO₂max. Because VO₂max is measured in kilograms relative to body weight, changes in body weight can also affect VO₂max. In addition, regulation of body fluids can change plasma volume and hemoglobin volume, which in turn can change the ability of the blood to transport oxygen. Potential changes in plasma volume can change heart rate, which is one of the important factors affecting cardiac output. Finally, the respiratory system needs oxygen from the lungs to the body, all of which are affected by the hormonal changes of the menstrual cycle.

Moran et al. (2000), by examining the cardiovascular function of 26 healthy women during the monthly period, showed that the resting heart rate during the ovulation and luteal phases has a significant increase compared to the menstrual and follicular phases, and the resting systolic blood pressure during the ovulation phase has a significant increase compared to the follicular and luteal phases [13]. Dimitriou et al (2007) also found significant results for heart rate in their study of the effect of different phases of the menstrual cycle on cardiovascular function. By examining the cardiovascular performance of 10 healthy women during the follicular and luteal phases in two consecutive months, they concluded that the subjects' resting heart rate was associated with a decrease in the follicular phase and an increase in the luteal phase. On the other hand, the results showed that despite the lack of influence of the menstrual cycle on blood pressure, sympathetic nerve activity is higher in the luteal phase than in the follicular phase. These investigators suggested that differences in menstrual hormone balance may account for these changes in autonomic function during the menstrual cycle [14]. Meanwhile, Licht et al. (2003) and Smikal et al. (2007) showed that different phases of the menstrual cycle do not have a significant effect on resting heart rate [15, 16].

Hiroshan et al (2002) also found no significant difference in resting systolic and diastolic blood pressure during 5 phases of the menstrual cycle [17]. Tersi et al (2003), while studying the blood lactate threshold in the early follicular, mid-follicular and mid-luteal phases of the monthly cycle in 8 healthy active women, showed that the

subjects' VO₂max was not affected by the monthly cycle [18]. Smikal et al (2007) also found no significant difference in subjects' heart rate and VO₂max during the menstrual cycle. The results of their research indicated that the subjects' VO₂max and heart rate during rest, exercise, and stagnation were not affected by the follicular and luteal phases of the menstrual cycle, although the ventilation during the luteal phase was higher than during the follicular phase [16]. However, Lebron et al (1995) previously found a significant difference in VO₂max between the follicular and luteal phases of the menstrual cycle, with VO₂max during the luteal phase being lower than during the follicular phase. However, maximum heart rate and maximum minute ventilation were not significantly different between the phases [19]. Anaerobic power also plays a special role in sports such as period activities and is of significant importance to many athletes. Bushman et al (2006) investigated the performance of anaerobic power during the menstrual and lutein phases of the menstrual cycle. The results of this research showed that peak power, anaerobic capacity, and average power estimated by the Wingate test did not differ significantly during the menstrual cycle [20]. Middleton and Wenger (2006) also investigated the effect of different phases of the menstrual cycle on the performance of intense periodic activity. The results indicated that the peak power did not have a significant difference during the menstrual period, while the average work done during the luteal phase was more than the follicular phase [21].

Therefore, considering the possibility of the effect of the physiological changes of the menstrual cycle on the athletic performance and the efficiency of the cardio-respiratory system of women, on the one hand, and the very limited and heterogeneous research results in this regard, on the other hand, the present research assumes the effect of the menstrual cycle on the physiological indicators of women and with the aim of Investigating the effect of different stages of the menstrual cycle on some physiological indicators (heart rate, blood pressure, maximum oxygen consumption and anaerobic capacity) of female athletes.

2. METHODOLOGY

Fifteen female athletes (mean age = 21.73 ± 3.7 years; height = 1.61 m; weight = 58.03 kg; body fat = 20.46%; BMI = 21.28 kg/m²) with at least three years of training experience and no history of hormonal or sexual medication use during the past six months voluntarily participated in this study by completing an informed consent form. All participants had regular menstrual cycles of 25–35 days. To ensure the normality of the menstrual cycles, gynecological consultations were conducted by an obstetric specialist. The specific menstrual phases were identified based on serum levels of estrogen and progesterone, measured at three stages: early follicular phase (EF; 2nd or 3rd day of menstruation), late follicular phase (LF; 1–2 days before ovulation), and mid-luteal phase (ML; 5–6 days after ovulation).

To minimize learning effects, participants were randomly divided into three groups, each beginning the tests in a different phase. Dietary intake and physical activity were controlled across all three phases. Each participant was asked to record her diet one day before testing and to replicate the same dietary pattern in subsequent sessions. In addition, participants were instructed to refrain from consuming caffeine, alcohol, or tobacco and from performing any physical exercise for 48 hours before testing, as well as to avoid food intake two hours prior to blood sampling.

Measured variables included resting heart rate, resting systolic and diastolic blood pressure, maximal oxygen uptake (VO₂max), and anaerobic power, all assessed in each of the three phases. Resting heart rate was recorded immediately after waking, and blood pressure was measured in the supine position after 30 minutes of rest before blood sampling. At each stage, height, weight, and body fat percentage were measured first. Then, VO₂max and anaerobic power were assessed using the Astrand–Rhyning maximal test and RAST test, respectively. Warm-up duration, testing order, and rest intervals were kept constant across all stages.

2.1. Astrand–Rhyning Test Procedure

Each participant pedaled at a workload of 20 W for 5 minutes as a warm-up. After a 5-minute rest, the test began at an initial workload of 24.5 W (150 kpm/min). The workload was increased by 24.5 W every 2 minutes until the participant's heart rate exceeded 70% of the predicted maximum ($220 - \text{age}$). Participants continued pedaling until their heart rate reached a steady state. The final workload and steady-state heart rate were used with the Astrand

nomogram (Appendix 1) to estimate oxygen consumption, and VO_{2max} was calculated using the following formula [22]:

$$VO_{2max} \text{ (L/min)} = 1.593 - [0.019 \times \text{age (years)}] - [0.302 \times \text{oxygen uptake from nomogram (L/min)}]$$

2.2. RAST Test Procedure

Prior to the RAST test, body weight was measured, and participants completed a 10-minute warm-up consisting of general stretching and dynamic movements, followed by 5 minutes of rest. Each participant then sprinted six 35-m runs at maximal effort, with 10 seconds of rest between each sprint. Sprint times were recorded to the nearest 0.01 second. Maximum and minimum power output (calculated as displacement \times body mass / time), mean power, and the fatigue index (total time / [minimum power – maximum power]) were computed for each participant [22].

2.3. Statistical Analysis

Descriptive statistics, repeated-measures ANOVA, and Bonferroni post-hoc tests were used to analyze the data. The significance level was set at $P \leq 0.05$.

3. RESEARCH RESULTS AND FINDINGS

The results of examining estrogen and progesterone hormone concentrations to determine the target phases of the menstrual cycle showed a significant difference in the concentrations of these hormones across the various stages of the cycle (Table 1).

Table 1. Results of repeated measures ANOVA for estrogen and progesterone hormones

Variable	F	df	P	Partial Eta Squared
Estrogen	64.357	2, 28	0.0005*	0.821
Progesterone	23.669	2, 13	0.0005*	0.785

Significant difference at $p < 0.05$

The findings revealed that estrogen levels increased significantly from the early follicular phase to the late follicular phase and significantly decreased from the late follicular to the mid-luteal phase. Moreover, the level of estrogen in the mid-luteal phase was significantly higher than in the early follicular phase. Progesterone levels also showed a significant increase from the early follicular to the late follicular phase, from the early follicular to the mid-luteal phase, and from the late follicular to the mid-luteal phase. The variations in each hormone across the three phases are illustrated in Figure 1.

Regarding the physiological indicators, the results indicated that there were significant differences in heart rate, systolic blood pressure, VO_{2max} , and maximum anaerobic power among the three phases of the menstrual cycle. However, diastolic blood pressure, minimum and mean anaerobic power, and the fatigue index did not show significant changes (Table 2). The mean differences for each physiological indicator are shown in Figure 2.

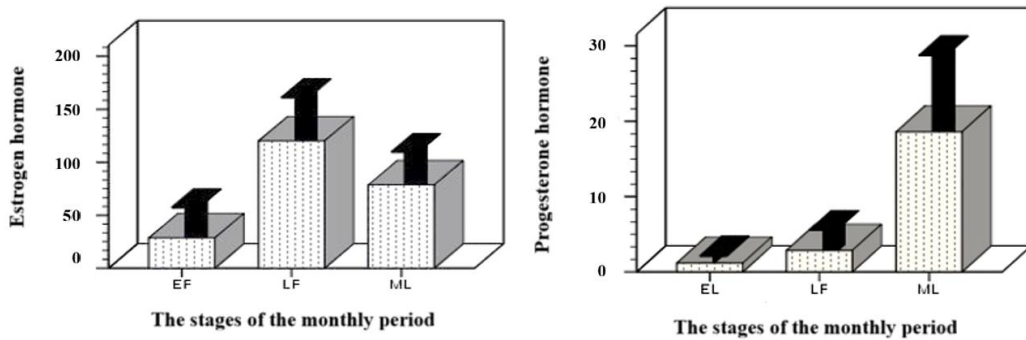


Chart 1. The average difference of estrogen (pg/ml) and progesterone (nmol/l) hormones between the stages of the monthly period

Table 2. Results of repeated measures ANOVA for physiological indicators

Variable	F	df	P	Partial Eta Squared
Resting heart rate	9.964	2, 28	0.001*	0.416
Systolic blood pressure	70.000	2, 28	0.0005*	0.833
Diastolic blood pressure	0.683	2, 28	0.513	0.047
VO ₂ max	16.460	2, 28	0.0005*	0.540
Maximum anaerobic power	3.957	2, 28	0.031*	0.220
Minimum anaerobic power	0.403	2, 28	0.672	0.028
Mean anaerobic power	1.107	2, 28	0.344	0.073
Fatigue index	2.421	2, 28	0.107	0.147

Significant difference at $p < 0.05$

The pairwise comparison of menstrual phases using the Bonferroni post hoc test revealed that participants’ resting heart rate differed significantly between the early follicular and mid-luteal phases, as well as between the late follicular and mid-luteal phases. However, there was no significant difference between the early and late follicular phases. The highest heart rate was observed during the mid-luteal phase, followed by the early follicular and late follicular phases.

Systolic blood pressure showed a significant increase from the early follicular to the late follicular phase and from the early follicular to the mid-luteal phase, while no significant difference was observed between the late follicular and mid-luteal phases. Similarly, VO₂max significantly increased from the early follicular to the late follicular phase and significantly decreased from the late follicular to the mid-luteal phase, though the difference between the early follicular and mid-luteal phases was not significant. Participants demonstrated the highest VO₂max during the late follicular phase (Table 3).

Table 3. Results of Bonferroni pairwise comparisons for heart rate, blood pressure, and VO₂max

Menstrual phase comparison	Heart rate (P)	Systolic BP (P)	Diastolic BP (P)	VO ₂ max (P)
EF–LF	1.067	0.0005*	1.000	0.003*
EF–ML	3.467*	0.0005*	0.611	1.000
LF–ML	4.533*	0.166	1.000	0.0005*

Significant difference at $p < 0.05$

Regarding maximum anaerobic power, a significant difference was observed only between the late follicular and mid-luteal phases, showing a decrease in maximum power from the late follicular to the mid-luteal phase. Although the repeated measures ANOVA did not show significant differences for the fatigue index, the Bonferroni test revealed a significant difference between the late follicular and mid-luteal phases, indicating a notable reduction in fatigue from the late follicular to the mid-luteal stage (Table 4).

Table 4. Results of Bonferroni pairwise comparisons for anaerobic power indices

Menstrual phase comparison	Max Power (P)	Min Power (P)	Mean Power (P)	Fatigue Index (P)
EF-LF	0.123	1.000	0.324	0.427
EF-ML	1.000	1.000	1.000	1.000
LF-ML	0.048*	1.000	0.946	0.048*

Significant difference at $p < 0.05$

Overall, the results indicate that hormonal fluctuations during different menstrual phases significantly affect physiological responses such as heart rate, systolic blood pressure, aerobic capacity, and anaerobic performance, while having limited influence on diastolic blood pressure and fatigue-related indices.

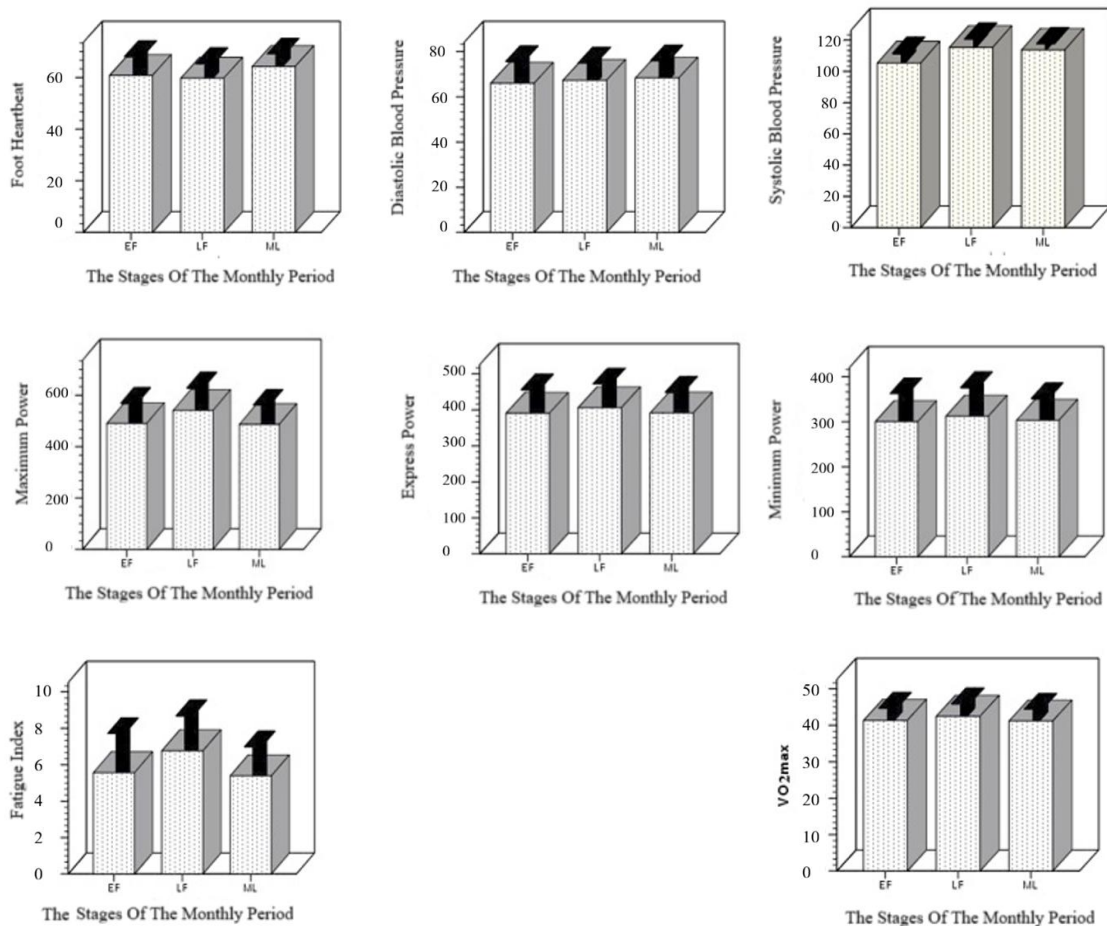


Chart 2. The difference in the mean of physiological indicators between the phases of the monthly period

4. DISCUSSION AND CONCLUSION

The present study aimed to investigate the effects of different phases of the menstrual cycle on selected physiological indicators (heart rate, blood pressure, maximal oxygen uptake, and anaerobic power) among female athletes. According to the obtained results, the levels of estrogen and progesterone significantly changed across the three menstrual phases ($p < 0.05$). Previous studies have shown that steroid hormones are at their lowest levels during the early follicular phase. Toward the end of the follicular phase, estrogen levels increase and reach their peak, whereas progesterone concentration remains relatively constant. Following ovulation, estrogen levels drop while progesterone levels increase, reaching their highest concentration in the mid-luteal phase [3, 23, 24]. The findings of this study are consistent with those reports, confirming the accurate identification of menstrual phases.

A significant difference in heart rate was observed among the three phases. Specifically, heart rate increased significantly from the early and late follicular phases to the mid-luteal phase, whereas no significant difference was found between the early and late follicular phases. These results are consistent with studies by Moran et al. (2000) and Dimitriu et al. (2007), who reported significantly higher resting heart rates during the luteal phase [13, 14]. However, the findings of Hirshon et al. (2002) [17], Smekal et al. (2007) [16], and Leicht et al. (2003) [15] showed no significant variation in heart rate across menstrual phases. Such discrepancies may be attributed to methodological differences in determining menstrual phases [13, 14], age, dietary habits [16], participants' fitness levels (athletes vs. non-athletes) [16, 17], the specific phases examined [16, 19], and sample sizes. Some studies did not employ reliable hormonal measurements to verify cycle phases [13, 14], while others involved participants with different physical fitness levels [14, 16, 17].

From a physiological perspective, progesterone plays a key role in increasing body temperature, and this thermogenic effect likely contributes to inter-phase variations in heart rate [3]. Research has shown that for every 1°C increase in body temperature, heart rate rises by approximately 7 beats per minute. Therefore, elevated body temperature in the luteal phase, along with increased catecholamine levels, may lead to higher heart rate responses [25]. Catecholamines such as epinephrine and norepinephrine enhance cardiac contractility and frequency, suggesting that elevated catecholamines during the luteal phase could be responsible for increased heart rate. Conversely, in the early follicular phase, menstrual blood loss (approximately 40–200 mL) reduces blood volume and oxygen-carrying capacity. Consequently, despite lower progesterone and body temperature, heart rate remains relatively stable to maintain sufficient circulation [5].

The findings regarding diastolic blood pressure showed no significant difference among menstrual phases, consistent with the results of previous studies [13, 14, 17]. Diastolic pressure appears to be less influenced by hormonal fluctuations, possibly due to the heart's prolonged relaxation phase during diastole, which is physiologically critical and tightly regulated [25].

In contrast, systolic blood pressure significantly increased from the early follicular to the late follicular and mid-luteal phases, with no significant difference between the late follicular and mid-luteal stages. These results align with findings from Hirshon et al. (2002) and Moran et al. (2000), but differ from Dimitriu et al. (2007). The likely explanation for this pattern involves estrogen's effect on aldosterone production. Elevated estrogen during the late follicular phase stimulates greater aldosterone secretion, which regulates sodium-water balance and plasma volume, thereby increasing blood pressure [3, 25]. In the mid-luteal phase, despite slightly lower estrogen compared to the late follicular stage, it remains higher than in the early follicular phase—thus maintaining higher systolic pressure. Additionally, decreased estrogen and blood loss during menstruation may contribute to lower systolic pressure in the early follicular phase [5].

The results of the Ryhming–Åstrand test indicated that the highest mean VO_2max occurred during the late follicular phase, followed by the mid-luteal and early follicular phases. Significant differences were found between the early and late follicular phases and between the late follicular and mid-luteal phases, while no significant difference appeared between the early follicular and mid-luteal stages. Nicholas et al. (1989) also reported a significant reduction in VO_2max from the follicular to luteal phases [26], and Lebrun et al. (1995) found lower VO_2max values in the luteal phase compared to the early follicular phase, attributing this difference to estrogen fluctuations [19]. However, many studies have found no significant impact of menstrual phases on VO_2max [18, 27, 28]. For example, Smekal et al. (2007) and Tresa et al. (2003) reported no significant changes in VO_2max between the follicular and luteal phases [16, 21].

Progesterone has been shown to increase ventilatory response (VE), yet its influence on exercise performance remains inconclusive [3, 29]. Beidleman et al. (1999) suggested that progesterone-induced increases in VE might improve oxygen delivery at altitude, though they did not observe corresponding VO₂max changes [30]. Differences in measurement methods, fitness levels, and phase determination may explain the inconsistencies across studies [16, 18, 21, 27, 28].

The observed VO₂max variations may be attributed to hormonal shifts. Estrogen elevation during the follicular phase enhances lipid metabolism, promoting aerobic energy production [3]. Thus, lower estrogen in the luteal phase corresponds with reduced VO₂max. Furthermore, progesterone-induced hyperthermia elevates heart rate—a variable integral to the Åstrand-Ryhming test—thereby influencing the estimation of VO₂max. Since increased heart rate reduces work output, it indirectly lowers calculated VO₂max during the luteal phase. Catecholamine variations may also contribute [3], yet in this study, progesterone-induced heart rate changes appear to be the dominant factor affecting VO₂max reduction.

RAST test results showed that minimum and mean anaerobic power were not significantly affected by menstrual phases, while maximum power and fatigue index decreased significantly in the mid-luteal phase compared to the late follicular phase. Bushman et al. (2006) found no significant variation in peak power or anaerobic capacity during the menstrual and luteal phases using the Wingate test [20]. Similarly, Giacomoni et al. (2000) observed no significant changes in peak cycling power or vertical jump height across menstrual stages [31]. Middleton and Wenger (2006) also found no significant difference in peak power, though total work done was higher during the luteal phase [21].

Discrepancies between studies may stem from differences in anaerobic testing protocols. Bushman et al. (2006) used the Wingate test [20], while the present study used the RAST test, which involves sprinting over 35 meters—thus introducing the potential influence of body mass changes. Weight gain during the luteal phase [3] may impair sprint performance, leading to lower peak power and reduced fatigue index.

In conclusion, the findings indicate that menstrual cycle phases significantly influence heart rate, resting systolic blood pressure, maximal oxygen uptake, and peak anaerobic power in female athletes. Coaches and sports scientists should consider these variations when designing training programs and evaluating athletes' physiological performance. Further research is recommended to control confounding variables and clarify the precise role of menstrual cycle phases in women's physiological responses.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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