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Analysis of Heart Rate Variability and Anaerobic Performance in Female Athletes Based on Menstrual Cycle Phases

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Abstract

This study aims to analyze differences in physiological performance, anaerobic performance, neuromuscular stability, and biomechanical risk indicators in female athletes based on the phase of the menstrual cycle. The study uses a quantitative approach with a cross-phase comparative design of the menstrual cycle. The measurement data totaled 36 and was divided evenly into three phases, namely the early menstrual/follicular phase, the ovulation phase, and the luteal phase. The variables measured included VO_2max as an indicator of aerobic capacity, vertical jump as an indicator of anaerobic performance, Y-Balance Test as an indicator of neuromuscular stability, and knee valgus angle as an indicator of lower extremity biomechanics risk. Data were analyzed using descriptive statistics, normality test, One-Way ANOVA, Tukey HSD follow-up test, and homogeneous subset analysis with a significance level of 0.05. The results showed that there were significant differences between the phases of the menstrual cycle in all variables. The ovulation phase shows the highest values in VO_2max and vertical jump, which indicates an increase in aerobic capacity and leg power. However, the same phase also showed a decrease in the Y-Balance Test and an increase in knee valgus angle, indicating an increased risk of biomechanics. The early menstrual/follicular phase tends to show lower performance, while the luteal phase is in a transitional position with relatively better stability than the ovulation phase. In conclusion, the menstrual cycle is an important variable in the performance evaluation and injury prevention of female athletes. Periodization of menstrual cycle-based exercise needs to be applied individually, ethically, and data-driven to optimize performance while reducing the risk of injury.

Keywords: female athletes; menstrual cycle; VO_2max; vertical jump; Y-Balance Test; knee valgus angle.

INTRODUCTION

Women's participation in competitive sports has increased significantly in recent decades, both at the school, college, club and elite competition levels. These developments have important consequences for sports science, namely the need for training approaches, performance monitoring, and injury prevention that are no longer structured based on the physiological assumptions of male athletes. Female athletes have distinctive biological characteristics, especially about fluctuations in reproductive hormones throughout the menstrual cycle. Changes in estrogen and progesterone levels in the early menstrual or follicular phases, ovulation, and luteal have the potential to affect energy metabolism, cardiovascular response, body temperature, muscle activation, motor control, psychological mood, and connective tissue stability. Therefore, the menstrual cycle cannot be viewed as just a routine biological event but needs to be understood as a physiological factor that can modulate exercise readiness, fatigue response, anaerobic performance, and injury risk in female athletes.

In the context of modern sports, athletes' performance is not only determined by physical abilities such as endurance, strength, speed, and power, but also by the body's ability to maintain a balance of autonomic and neuromuscular nervous systems. Heart rate variability (HRV) is widely used as a non-invasive indicator to look at autonomic regulation, recovery status, physiological stress, and exercise readiness. Mishica et al. (2022) suggest that measurements of heart rate index and HRV can be a long-term monitoring tool in young athletes, while Gorgulu et al. (2024) assert that competitive pressure can alter athletes' autonomic cardiac activity. These findings strengthen HRV's position as an important indicator in understanding the body's response to training load and match pressure. In female athletes, the HRV interpretation becomes more complex because autonomic responses can interact with hormonal changes throughout the menstrual cycle. Sims et al. (2021) also emphasized that recovery metrics such as HRV, resting heart rate, respiration rate, and sleep duration need to be understood in relation to ovarian hormone modulation in female athlete populations.

The main problem in coaching female athletes is the limited integration of menstrual cycle information into training planning and performance evaluation. Many training programs still apply a general approach that does not differentiate between the physiological needs of male and female athletes. As a result, certain phases in the menstrual cycle are often not considered when the trainer sets the intensity of the exercise, the volume of the exercise, the schedule of physical tests, or the injury prevention strategy. In fact, recent studies have shown that the phases of the menstrual cycle can be related to changes in aerobic, anaerobic, strength, flexibility, and psychophysiological responses, although the results still show variation between individuals and methodological differences (Wen et al., 2025). This raises practical problems: coaches need more specific data to determine when athletes can be given high-intensity stimulus, when weight adjustments are needed, and when to be given stabilization or recovery interventions.

Another issue that is no less important is the increased risk of lower extremity injuries in female athletes, especially knee and ankle injuries. Hormonal changes are thought to affect ligament elasticity, tissue stiffness, postural control, and landing patterns. Maruyama et al. (2022) reported that the menstrual cycle is related to changes in joint laxity, both in non-athlete and athlete women. Hartman et al. (2024) also highlight a possible link between hormonal fluctuations, ligamentous laxity, and ankle instability in women. From a biomechanics perspective, a decrease in neuromuscular control can increase the angle of the knee valgus when athletes perform explosive movements such as jumping, landing, sprinting, and changing direction. This is relevant to sports games, including basketball, which demand acceleration, deceleration, jumping, body contact, and repetitive changes of direction. If the biological phase of an athlete is not monitored, an increase in performance in a certain phase can occur along with an increase in injury susceptibility.

The latest literature offers several directions for solutions. First, menstrual cycle monitoring needs to be positioned as part of the training monitoring system for female athletes, not as personal information separate from performance coaching. The use of menstrual calendars, symptom recording, basal temperature measurements, ovulation validation, and monitoring of physiological indicators can help coaches understand the variations in athletes' responses. Second, periodization of menstrual cycle-based exercise is starting to be widely recommended as an individual approach. Wen et al. (2025) explain that reproductive hormones can affect performance through substrate metabolism, cardiopulmonary function, body temperature regulation, and psychological factors. Thus, the training program should not only refer to the competition calendar but also consider the biological readiness of the athlete.

Third, the literature on female athletes' performance shows the importance of selecting comprehensive test indicators. HRV can describe the recovery status and regulation of autonomic nerves, while anaerobic tests such as vertical jump or countermovement jump can indicate the power production ability of the lower extremities. In addition, dynamic balance tests such as the Y-Balance Test and analysis of knee valgus biomechanics can provide information about neuromuscular control and potential injury risk. Newbould et al. (2025) emphasize the need for standardization of menstrual cycle phases in muscle-tendon unit assessments in female athletes because the reliability of measurements can be influenced by biological conditions. Soedirdjo et al. (2023) also show that sex hormones are related to the dynamics of muscle activation and deactivation, so performance evaluation should not only measure movement outcomes, but also consider the underlying neuromuscular mechanisms.

Fourth, exercise-based research shows that the effects of menstrual cycles are not always uniform. Igonin et al. (2022) found that the phase of the menstrual cycle can affect the movement patterns of female football players in competitive matches. Yanez et al. (2026) report that the menstrual cycle is related to internal and external loads in female CrossFit athletes in real training situations. In recreational basketball players, the early follicular and late follicular phases are reported to produce differences in shoulder agility and endurance. These findings suggest that the impact of the menstrual cycle needs to be studied based on the characteristics of the sport, the type of test, and the demands of movement. Basketball as a high-intensity intermittent sport requires cardiovascular endurance, anaerobic ability, coordination, agility, and joint stability at the same time. Therefore, the analysis of menstrual cycles in female basketball athletes has strong scientific and practical relevance.

Although the literature has shown the importance of paying attention to the menstrual cycle in women's sport, there are still a few gaps. First, some studies still use a general, perception-based approach, or only compare one-two phases of the cycle, so they do not fully describe the changes in performance across the phases of menstruation, ovulation, and luteal. Second, many studies assessed performance separately, for example focusing only on endurance, strength, or agility, without integrating cardiovascular, anaerobic, neuromuscular stability, and injury risk indicators in a single measurement design. Third, evidence on the link between improved performance and increased risk of injury still needs to be strengthened. The ovulation phase, for example, is often associated with an increase in estrogen that can support certain performance, but at the same time can affect ligament laxity and joint control. In other words, the favorable phase for power production is not necessarily the most biomechanically safe phase.

This gap is becoming increasingly important in the context of coaching female athletes in Indonesia. The discussion of menstruation in the training environment is still often considered sensitive, taboo, or only seen as an individual athlete's complaint. As a result, coaches do not yet have a systematic habit of recording cycle phases, linking them to performance, and making them the basis for training decision-making. In addition, empirical data on Indonesian female athletes, especially in sports such as basketball, is still limited. In fact, the characteristics of the training environment, health monitoring habits, coaches' understanding, and athletes' readiness to report menstrual conditions can differ from the context of other countries. Therefore, a study is needed that presents quantitative evidence regarding differences in HRV, aerobic capacity, anaerobic power, dynamic stability, and injury biomechanical indicators based on the phases of the menstrual cycle.

Based on this description, this study aims to analyze differences in cardiovascular indicators, anaerobic performance, neuromuscular stability, and injury risk in female athletes based on the phase of the menstrual cycle. Specifically, this study was directed to test changes in

VO_2max, vertical jump, Y-Balance Test, and knee valgus angle in the early menstrual or follicular phases, ovulation, and luteal. The novelty of this study lies in the integration of several performance indicators and injury risk in one analysis framework based on the phases of the menstrual cycle. By combining physiological aspects, explosive performance, dynamic balance, and knee biomechanics, the study sheds light not only on when an athlete's performance increases or decreases, but also when an increase in performance can be followed by an increase in injury susceptibility.

The scope of this study is focused on female athletes with regular menstrual cycles and performance measurements carried out in a structured manner in the main phases of the cycle. This article is expected to contribute to the development of women's sports science, especially in the preparation of more individualized, adaptive, and data-based exercise periodization. In practical terms, the results of the study can be the basis for coaches, athletes, and sports practitioners to optimize training intensity, determine physical test schedules, develop recovery strategies, and add injury prevention exercises in more vulnerable phases. Thus, understanding the menstrual cycle is not only beneficial for maintaining athletes' reproductive health, but also an important component in managing the performance and career sustainability of female athletes.

METHODS

Research Design

This study uses a quantitative approach with a comparative design across phases of the menstrual cycle. This design was chosen because the purpose of the study was to analyze differences in physiological indicators, anaerobic performance, neuromuscular stability, and biomechanical risk in female athletes based on the phases of the menstrual cycle. The phases analyzed included phase 1 or early menstruation/follicular phase, phase 2 or ovulation, and phase 3 or luteal. The quantitative approach allows each variable to be objectively measured through field tests and statistical analysis. The selection of this design is also in line with women's sports research recommendations that emphasize the importance of menstrual cycle phase control when assessing athletes' performance, recovery, and physiological responses (Carmichael et al., 2021; Sims et al., 2021). In addition, studies on female athletes need to pay attention to hormonal variations because changes in estrogen and progesterone can affect cardiovascular function, neuromuscular response, energy metabolism, and connective tissue stability (Rael et al., 2021; Wen et al., 2025).

Participants

The study participants were female athletes who actively participated in game sports training, especially sports with the demands of jumping, change of direction, acceleration, deceleration, and high-intensity intermittent activities. The number of measurement data analyzed was 36 data, which were divided evenly into three phases of the menstrual cycle, namely 12 data in phase 1, phase 2, and phase 3 respectively. The inclusion criteria for participants include: (1) female; (2) actively participate in training programs regularly; (3) have a regular menstrual cycle in the range of 21–35 days; (4) not currently using hormonal contraceptives; (5) have not suffered a musculoskeletal injury of the lower extremities in the last six months; and (6) willing to take the entire series of tests according to the schedule of the menstrual cycle phase. Exclusion criteria include severe menstrual disorders, a history of unrecovered knee or ankle injury, consumption of hormonal medications, or absence from one of the measurement sessions. The criteria were set to minimize physiological bias and ensure that the observed performance changes were more likely to relate to the phases of the menstrual cycle, rather than other external factors.

Procedure

The research procedure began with socialization to participants about the objectives, benefits, measurement stages, and confidentiality of data related to the menstrual cycle. After expressing their willingness, participants are asked to fill out an approval sheet and a short medical history form. Furthermore, the researcher recorded the menstrual cycle through the menstrual calendar and confirmed the phase based on information on the first day of the last menstrual period. Phase 1 is identified in the early menstrual or follicular period, phase 2 in the period around ovulation, and phase 3 in the luteal period. Where available, phase identification can be strengthened with basal temperature recording or menstrual cycle monitoring applications. This monitoring approach is in line with recent studies that emphasize the importance of hormonal and menstrual cycle monitoring in female athlete performance research (Nagorna et al., 2026; Schlie et al., 2026).

Each participant underwent measurements under uniform striving conditions, such as relatively similar test times, same warm-up instructions, and strenuous activity restrictions before the test. Prior to the main data collection, participants underwent a standard 10–15-minute warm-up consisting of light jogging, dynamic mobility, leg muscle activation, and test-specific movements. The sequence of tests was arranged to reduce the effects of fatigue, starting from the measurement of physiological indicators, followed by power tests, dynamic balance tests, and observation of knee biomechanics. Each test is given sufficient rest time so that the measurement results are not affected by acute fatigue. This procedure aims to maintain the reliability of the data and ensure that the differences in results between phases can be interpreted more accurately.

Instruments

The research instrument consists of four main groups. First, aerobic capacity is measured through VO_2max estimation using relevant field tests, such as the Multi-Stage Fitness Test or equivalent procedures that can describe the cardiorespiratory capacity of athletes. VO_2max is used because it is an important indicator of the body's ability to transport and use oxygen during moderate to high intensity physical activity. Previous studies have shown that cardiorespiratory responses in female athletes can differ between phases of the menstrual cycle, so relevant VO_2max is used as the primary physiological variable (Rael et al., 2021).

Second, anaerobic performance was measured using the Vertical Jump Test. This test is used to assess the power ability of the lower extremities, especially the ability to generate force quickly through the explosive mechanism of the leg muscles. Vertical jump is a practical indicator in sports games because it relates to the ability to jump, rebound, accelerate, and explosive movements. The use of power tests is also in accordance with the study of anaerobic performance in female athletes which emphasizes the importance of power measurement in evaluating neuromuscular readiness (Bougrine et al., 2025; Korkmaz et al., 2025).

Third, neuromuscular stability was measured using the Y-Balance Test. This test assesses an athlete's ability to maintain dynamic balance in three directions of range, as well as describe postural control, lower extremity coordination, and joint stability during functional activity. A lower Y-Balance Test score may indicate decreased neuromuscular control and a potential increased risk of injury. Fourth, the risk of knee biomechanics is measured through the knee valgus angle. This measurement is made by observing the position of the knee during functional movements such as landing or movement tasks involving knee flexion. The knee valgus angle is used because the greater valgus angle of the knee is often associated with increased load on the passive structure of the knee, especially in explosive movements and changes of direction. The literature on lower extremity injuries in female athletes emphasizes that changes in ligamentous laxity and neuromuscular control can be affected by the phases of the menstrual cycle (Maruyama et al., 2022; Nédélec et al., 2021).

Data Analysis

The data were analyzed quantitatively using descriptive and inferential statistics. Descriptive statistics are used to obtain the minimum, maximum, mean, and standard deviation values of each variable. Normality tests were performed using Kolmogorov-Smirnov and Shapiro-Wilk to determine the distribution of data. After that, the differences between phases of the menstrual cycle were analyzed using One-Way ANOVA because the study compared an average of more than two phase groups. If the ANOVA results show significant differences, the analysis is followed by the post-hoc Tukey HSD test to find out the different phase pairs meaningfully. In addition, homogeneous subset analysis is used to group phases based on the average proximity of each variable. The level of statistical significance was set at $\alpha = 0.05$. The interpretation of the results is not only based on the p-value, but also on the direction of the change in the mean and its practical significance for the performance and risk of injury of female athletes.

RESULTS

The results of this study were compiled to present empirical findings regarding differences in physiological performance, anaerobic performance, neuromuscular stability, and injury risk indicators based on the phase of the menstrual cycle. The research subjects amounted to 36 measurement data divided into three groups of menstrual cycle phases, namely phase 1, phase 2, and phase 3, each with 12 measurement data. In the interpretation of this study, phase 1 refers to the early menstrual/follicular phase, phase 2 refers to the ovulation phase, and phase 3 refers to the luteal phase. The variables analyzed included VO_2max, vertical jump, Y-Balance Test, and knee valgus angle.

Descriptive statistics show that the average VO_2max value of all measurement data is 42.45 ± 2,166 ml/kg/min, vertical jump of 41.08 ± 3,279 cm, Y-Balance Test of 88.21 ± 3.508%, and knee valgus angle of 12.96 ± 2.493°. The range of values shows quite clear variation in performance across all variables, especially in vertical jump and knee valgus angle. This variation indicates that the phase of the menstrual cycle has the potential to be related to changes in the physiological and biomechanical responses of female athletes.

Table 1. Descriptive statistic

	N	Minimum	Maximum	Mean	Std. Deviation
VO2max	36	38	47	42.45	2.166
Vertical jump	36	35	48	41.08	3.279
Y_balance.test	36	81	94	88.21	3.508
Knee algus angel	36	9	17	12.96	2.493
Valid N (listwise)	36				

Based on Table 1, VO_2max and vertical jump showed relatively high average values, indicating that the subjects had a fairly good aerobic capacity and leg power. However, the value of the knee valgus angle which has a range of 9° to 17° indicates a variation in the pattern of knee biomechanics that needs to be considered in the context of injury risk. In athlete performance studies, HRV measurements, aerobic capacity, and power tests such as countermovement jumps or vertical jumps are often used as indicators of athletes' physiological and neuromuscular readiness (Mishica et al., 2022). Therefore, the combination of VO_2max, vertical jump, Y-Balance Test, and knee valgus angle variables in this study provides a more comprehensive picture of the relationship between menstrual cycle phases, performance, and injury risk.

The normality test was performed using Kolmogorov-Smirnov and Shapiro-Wilk. The results of the Shapiro-Wilk test showed that the VO_2max, vertical jump, and Y-Balance Test data were normally distributed because they had a significance value greater than 0.05. However, the knee valgus angle variable has a significance value of 0.001 at Shapiro-Wilk, so the data of this variable is not strictly distributed normally. Nevertheless, the ANOVA analysis is still presented because the research design aims to compare the averages between phases, the amount of data of each group is balanced, and the results are used as the basis for initial interpretation. In scientific publications, these findings need to be supplemented with interpretive caution, or additional non-parametric analysis may be considered at the statistical revision stage.

Table 2. Test of normality result

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VO2max	.058	36	.200*	.987	36	.939
Vertical jump	.062	36	.200*	.979	36	.698
Y_balance test	.095	36	.200*	.971	36	.441
Knee valgus angel	.203	36	.001	.874	36	.001

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The normality results show that most of the variables meet the parametric assumptions. This supports the use of ANOVA to test for performance differences based on the phases of the menstrual cycle. However, because the knee valgus angle is abnormal, the interpretation of the results on this variable needs to be focused on the direction of change and practical significance, not just on the statistical significance. Irregularities in the distribution of the knee valgus angle can occur due to the biomechanical response of the knee being highly individual and influenced by muscle strength factors, neuromuscular control, exercise experience, landing patterns, as well as possible changes in ligamentous laxity during the menstrual cycle. Recent literature also confirms that hormonal fluctuations may be associated with changes in joint laxity and risk factors for knee injury in women (Maruyama et al., 2022; Nédélec et al., 2021).

Differences in Research Variables Based on Menstrual Cycle Phases

The ANOVA One-Way test showed that there were significant differences in all research variables based on the phase of the menstrual cycle. VO_2max shows a significant difference between phases with values $F = 5.161$ and $p = 0.011$. Vertical jumps also showed significant differences with values of $F = 6.705$ and $p = 0.004$. The Y-Balance Test showed significant differences with values of $F = 6.378$ and $p = 0.005$. The strongest difference was found in the knee valgus angle with a value of $F = 197.048$ and $p < 0.001$. These findings suggest that the phases of the menstrual cycle are not only related to aerobic capacity and anaerobic power, but also to the dynamic stability and biomechanical patterns of the knee.

Table 3. One-way anova

		Sum of Squares	df	Mean Square	F	Sig.
VO2max	Between Groups	39.120	2	19.560	5.161	.011
	Within Groups	125.070	33	3.790		
	Total	164.190	35			
Vertical jump	Between Groups	108.720	2	54.360	6.705	.004
	Within Groups	267.530	33	8.107		
	Total	376.250	35			
Y_balance test	Between Groups	120.080	2	60.040	6.378	.005
	Within Groups	310.648	33	9.414		
	Total	430.728	35			
Knee valgus angel	Between Groups	200.720	2	100.360	197.048	.000
	Within Groups	16.807	33	.509		
	Total	217.527	35			

ANOVA results show that changes in the phases of the menstrual cycle are associated with changes in performance and stability. In the VO_2max variable, the presence of significant differences indicates that the cardiovascular response of female athletes can change according to hormonal phases. These results are relevant to the findings of Rael et al. (2021), who stated that the phases of the menstrual cycle can affect cardiorespiratory responses during exercise in trained women. In the vertical jump, a significant difference shows that the power production capacity of the limb also changes between phases. These findings are in line with Wen et al. (2025), who explain that female reproductive hormones can affect performance through neuromuscular, metabolic, and thermoregulatory mechanisms. In the Y-Balance Test and knee valgus angle, significant results showed that the cycle phase was also related to postural control, dynamic stability, and injury risk indicators. This condition reinforces the importance of combining performance evaluation and injury risk evaluation in one monitoring framework for female athletes.

Tukey HSD Advanced Test

The follow-up test of Tukey HSD was carried out to find out the phase pairs that had significant differences. At VO_2max, a significant difference was found between phase 1 and phase 2 with a mean difference of -2,500 and p = 0.010. In the vertical jump, significant differences were also found between phase 1 and phase 2 with a mean difference of -4,200 and p = 0.003. In the Y-Balance Test, phase 1 is significantly different from phase 2, while phase 2 is also significantly different from phase 3. In the knee valgus angle, all comparisons between phases show significant differences. These findings confirm that phase 2 is the most different phase compared to other phases, both in improving performance and increasing injury risk indicators.

Table 4. Multiple Comparisons, tukey HSD

Dependent Variable	(I) Menstrual cycle phases	(J) Menstrual cycle phases	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
VO2max	1	2	-2.500*	.795	.010	-4.45	-.55
		3	-.800	.795	.578	-2.75	1.15
	2	1	2.500*	.795	.010	.55	4.45
		3	1.700	.795	.097	-.25	3.65
	3	1	.800	.795	.578	-1.15	2.75
		2	-1.700	.795	.097	-3.65	.25
Vertical jump	1	2	-4.200*	1.162	.003	-7.05	-1.35
		3	-1.500	1.162	.410	-4.35	1.35
	2	1	4.200*	1.162	.003	1.35	7.05
		3	2.700	1.162	.066	-.15	5.55
	3	1	1.500	1.162	.410	-1.35	4.35
		2	-2.700	1.162	.066	-5.55	.15
Y_balance test	1	2	4.100*	1.253	.007	1.03	7.17
		3	.500	1.253	.916	-2.57	3.57
	2	1	-4.100*	1.253	.007	-7.17	-1.03
		3	-3.600*	1.253	.019	-6.67	-.53
	3	1	-.500	1.253	.916	-3.57	2.57
		2	3.600*	1.253	.019	.53	6.67
Knee valgus angel	1	2	-5.500*	.291	.000	-6.21	-4.79
		3	-1.200*	.291	.001	-1.91	-.49
	2	1	5.500*	.291	.000	4.79	6.21
		3	4.300*	.291	.000	3.59	5.01
	3	1	1.200*	.291	.001	.49	1.91
		2	-4.300*	.291	.000	-5.01	-3.59

*. The mean difference is significant at the 0.05 level.

The results of Tukey HSD show that the increase in VO_2max and vertical jump mainly occurs from phase 1 to phase 2. Phase 1 can be interpreted as a phase with relatively lower performance, while phase 2 is a phase with peak performance. However, in the Y-Balance Test variable, phase 2 showed a decrease in dynamic stability compared to phase 1 and phase 3. Consistent differences in knee valgus angle show that changes in knee biomechanics are highly sensitive to the phases of the menstrual cycle. Thus, the results of the study not only show the "best phases" for performance but also show phases that require higher awareness of the risk of injury.

Homogeneous Subset Analysis

Homogeneous subset analysis clarifies the grouping of phases based on average proximity. In VO_2max and vertical jump, phase 1 tends to be in the lower performance subset, phase 2 is in the higher performance subset, and phase 3 is in the transition position. In the Y-Balance Test, phase 2 is in the lowest subset, while phase 1 and phase 3 are in the higher subset. In the knee valgus angle, the three phases are in different subsets, indicating a strong and consistent average difference in each phase.

Table 5. Homogeneous subset Vo2Max

Tukey HSD[a]

Phases of the menstrual cycle	N	Subset for alpha = 0.05: 1	Subset for alpha = 0.05: 2
1	12	41.35	
3	12	42.15	42.15
2	12		43.85
Sig.		.578	.097

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 12.000.

In the VO_2max variable, phase 1 has an average value of 41.35 ml/kg/min, phase 3 of 42.15 ml/kg/min, and phase 2 of 43.85 ml/kg/min. The homogeneous subset results show that phase 1 is on a lower performance subset, while phase 2 is on a higher performance subset. Phase 3 is in a transition position because its value is between phase 1 and phase 2. These findings suggest that female athletes' aerobic capacity tends to increase in phase 2 or the ovulation phase. The increase in VO_2max in this phase can be interpreted as a physiological condition that better supports the ability to transport and utilize oxygen during physical activity. In contrast, phase 1 or the early menstrual/follicular phase shows the lowest values, which can be related to physiological conditions such as menstrual discomfort, hormonal changes early in the cycle, and a possible decrease in the body's readiness for high-intensity activity. In practical terms, these results suggest that phase 2 can be a relatively favorable phase for exercise with higher cardiorespiratory endurance demands. However, phase 3 still shows enough capacity that it can be positioned as a medium to high training phase, depending on the individual condition of the athlete.

Table 6. Homogeneous subset vertical jump

Tukey HSD[a]

Phases of the menstrual cycle	N	Subset for alpha = 0.05	
		1	2
1	12	39.18	
3	12	40.68	40.68
2	12		43.38
Sig.		.410	.066

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 12.000.

In the vertical jump variable, phase 1 had an average of 39.18 cm, phase 3 of 40.68 cm, and phase 2 of 43.38 cm. The homogeneous subset pattern shows that phase 1 is in the lower leg power performance group, phase 2 is in the highest performance group, while phase 3 is back in the position between the two phases. These results show that the explosive ability of female athletes' limbs increases the highest in phase 2. Vertical jump is an indicator of anaerobic performance and lower extremity power, so an increase in the ovulation phase can indicate a more optimal neuromuscular condition. The activation of the unit's motor, coordination of muscle contractions, and the ability to generate force quickly are likely to be better in this phase. However, the increase in vertical jump in phase 2 needs to be interpreted with caution as high explosive performance can increase mechanical demands on the knee and ankle joints. Thus, phase 2 can indeed be used for power development, but it needs to be accompanied by landing technique control, joint stabilization, and injury prevention exercises.

Table 7. Homogeneous subset Y-balance.test

Tukey HSD[a]

Phases of the menstrual cycle	N	Subset for alpha = 0.05	
		1	2
1	12	85.64	
3	12		89.24
2	12		89.74
Sig.		1.000	.916

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 12.000.

In the Y-Balance Test variable, phase 2 showed the lowest average value, which was 85.64%, while phase 3 had a value of 89.24% and phase 1 had the highest value of 89.74%. In contrast to VO_2max and vertical jump, the homogeneous subset pattern in the Y-Balance Test shows that phase 2 is at a lower stability subset, while phase 1 and phase 3 are at a higher subset. These findings suggest that although phase 2 is the phase with the highest aerobic and anaerobic performance, it shows a decrease in dynamic stability. The Y-Balance Test describes an athlete's ability to maintain balance, postural control, lower extremity coordination, and neuromuscular stability during dynamic movements. Lower values in phase 2 indicate a decrease in neuromuscular control or increased joint instability. Scientifically, this result is important because it shows a paradoxical pattern. Athletes can have high power abilities and aerobic capacity, but at the same time experience decreased stability. Therefore, phase 2 needs to be understood not only as a peak performance phase, but also as a phase that requires biomechanical supervision and proprioceptive exercises.

Table 8. Homogeneous subset knee valgus angel

Tukey HSD[a]

Phases of the menstrual cycle	N	Subset for alpha = 0.05		
		1	2	3
1	12	10.73		
3	12		11.92	
2	12			16.22
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 12.000.

In the variable knee valgus angle, phase 1 has an average of 10.73°, phase 3 is 11.92°, and phase 2 is 16.22°. The homogeneous subset results show that the three phases are on different subsets. This means that each phase has distinctly different characteristics of the valgus angle of the knee. Phase 1 shows the lowest value of knee valgus angle, so it can be interpreted as a phase with a relatively more stable knee position or a smaller biomechanical risk. Phase 3 showed an increase in valgus angle compared to phase 1, but it was still much lower than phase 2. Meanwhile, phase 2 showed the highest value, which indicated an increased risk of biomechanics in the knee. Increased knee valgus angle in phase 2 needs to be of concern because a larger knee valgus angle is often associated with increased pressure on the knee's passive structure, especially the anterior cruciate ligament or ACL. If this condition occurs when an athlete performs a jump, landing, change of direction, or other explosive movements, then the risk of injury may increase. Thus, phase 2 is a phase that requires a stricter injury prevention strategy, although in this phase physical performance is seen to be higher.

The results of the homogeneous subset make it clear that phase 2 has unique characteristics: physiological and anaerobic performance is improved, but neuromuscular stability decreases and knee valgus angle is sharply improved. These findings show a paradoxical pattern in the performance of female athletes. On the one hand, phase 2 looks favorable for performance achievements such as VO_2max and vertical jump. On the other hand, the same phase displays a higher risk indicator of injury. This pattern is in line with the view of Carmichael et al. (2021) and Wen et al. (2025) that the influence of the menstrual cycle on athlete performance is not simple, but is influenced by the interaction between hormones, nervous system, metabolism, body temperature, and individual characteristics.

Overall, the results of the study show four main findings. First, the phase of the menstrual cycle is significantly related to aerobic capacity which is shown through the difference in VO_2max between phases. Second, the menstrual cycle phase is also significantly related to anaerobic performance, characterized by the difference in vertical jump between phases. Third, neuromuscular stability underwent significant changes, with the lowest Y-Balance Test score in phase 2. Fourth, the knee valgus angle shows the strongest difference between phases, with the highest value in phase 2. Thus, phase 2 can be understood as a high-performance phase as well as a high-risk biomechanics phase.

The scientific implication of these results is that monitoring female athletes needs to combine performance indicators and injury risk indicators simultaneously. Using VO_2max or vertical jump alone can lead the trainer to conclude that phase 2 is the most ideal phase for high-intensity training. However, when the Y-Balance Test and knee valgus angle data were included, phase 2 also appeared to be a phase that required injury prevention interventions, such as stabilization exercises, proprioceptive, landing control, hamstring strengthening, and correction of direction-change techniques. Therefore, the results of this study support a menstrual cycle-based exercise periodization approach that not only pursues peak performance but also maintains the sustainability of women's health and careers.

From the point of view of scientific publications, these results reinforce the urgency of using measurement designs that consider the phases of the menstrual cycle in women's sports research. Standardization of measurement phases is important because performance and biomechanics data can differ meaningfully between phases. If the cycle phase is not controlled, the results of the physical test of female athletes can experience interpretation bias. In line with Newbould et al. (2025), standardization of the menstrual cycle in neuromuscular assessment is needed to improve the reliability of performance data. Thus, this study provides an empirical basis that performance evaluation of female athletes should be carried out individually, longitudinally, and sensitive to the biological dynamics of the menstrual cycle.

DISCUSSION

The findings of this study show that the phase of the menstrual cycle is related to changes in physiological performance, anaerobic performance, neuromuscular stability, and biomechanical risk indicators in female athletes. Rationally, this pattern can be understood because the menstrual cycle is not just a reproductive process but is a biological mechanism that involves periodic changes in levels of the hormone's estrogen and progesterone. These hormonal changes can affect the cardiovascular system, energy metabolism, nerve-muscle function, body temperature, perception of fatigue, and connective tissue characteristics. Therefore, the difference in performance between phases is a logical phenomenon in the context of women's sports physiology.

In the ovulation phase, this study showed a tendency for better physiological and anaerobic performance. Biologically, the ovulation phase is often associated with an increase in estrogen. Estrogen has a potential role in supporting vascular function, increasing the efficiency of oxygen use, and influencing neuromuscular contractions and activation. This condition may explain why aerobic capacity and explosive performance tend to be higher in these phases. In game sports such as basketball, aerobic abilities are needed to maintain movement intensity during a game, while anaerobic abilities and leg power are needed to perform short sprints, jumps, changes of direction, rebounds, and quick transitions. Thus, the increase in performance in the ovulation phase has a strong physiological and practical basis.

However, the results of this study also show that improved performance in the ovulation phase is not always accompanied by increased neuromuscular stability. Precisely in the same phase, dynamic stability tends to decrease, and the knee valgus indicator increases. This pattern shows the existence of a paradoxical phenomenon, namely phases that support high performance while increasing biomechanical risk. Rationally, this condition can occur because hormones that contribute to performance enhancement also have the potential to affect connective tissue elasticity and joint control. When the ability to generate force increases, but neuromuscular control and joint stability decreases, then the mechanical load on the lower extremities may increase. In sports situations that require repetitive jumps, landings, acceleration, and changes of direction, these conditions can increase the risk of injury, especially in the knee.

These findings are important because they provide an understanding that it is not enough to evaluate female athletes just by looking at performance indicators. If the trainer only pays attention to an increase in VO_2max or vertical jump, the ovulation phase can be considered the most optimal phase for high-intensity exercise. However, when stability indicators and knee valgus angle are also analyzed, the same phase also needs to be understood as a phase that requires technical supervision and injury prevention interventions. Therefore, the results of this study confirm that the approach to coaching female athletes must be multidimensional, which combines aspects of performance, recovery, stability, and injury risk.

The early menstrual or follicular phase in this study showed a tendency to perform lower than the ovulation phase. This can be explained through several possibilities. First, some athletes experience discomfort, pain, mood swings, or decreased energy at the beginning of the cycle. Second, physiological conditions such as blood loss, changes in hormone levels, and menstrual symptoms can affect the body's readiness to perform high-intensity activities. Third, the response to menstruation is so individual that not all athletes experience the same decline. However, in general, these results reinforce the importance of monitoring the subjective condition of athletes in the early phases of the cycle to keep training safe and effective.

The luteal phase tends to indicate a transition position. On the one hand, performance is not as high as the ovulation phase; On the other hand, stability appears to be better than the ovulation phase. The luteal phase is often associated with increased progesterone and changes in basal body temperature. Progesterone can affect thermoregulation, perception of fatigue, and comfort during exercise. Therefore, the decrease in relative performance in the luteal phase can be interpreted as the body's response to hormonal changes and internal physiological loads. Thus, the overall empirical pattern of this study is rational because it reflects the interactions between hormones, energy systems, neuromuscular function, and biomechanical control.

The findings of this study have strong support from several Scopus studies that place the menstrual cycle as an important variable in the performance of female athletes. In the cardiovascular aspect, Rael et al. (2021) reported that the phase of the menstrual cycle can affect the cardiorespiratory response during exercise in trained women. The findings are relevant to the results of this study because aerobic capacity appears to change between phases. Tagliapietra et al. (2024) also showed that the phases of the menstrual cycle can affect physiological responses at rest as well as during submaximal exercise, especially when the body faces environmental conditions that demand greater oxygen and thermoregulation regulation. Morrison et al. (2023) added that changes in the menstrual cycle may be related to variations in cardiac structure and function in physically active women. Thus, changes in cardiovascular performance in this study can be understood as part of a broader physiological response, rather than just momentary fitness fluctuations.

Additional support was obtained from research on HRV and autonomous regulation. Sims et al. (2021) emphasize that recovery indicators such as HRV, resting heart rate, respiration, and sleep duration need to be understood along with ovarian hormone modulation. Meng et al. (2022) showed that attitudes toward menstruation and cognitive-social stress can affect the autonomic nervous system in women with premenstrual syndrome. In the athlete population, Gorgulu et al. (2024) found that competitive pressure can alter autonomic cardiac activity, while Tai et al. (2022) reported differences in HRV, arterial stiffness, and aerobic capacity between male and female badminton athletes. Javaloyes et al. (2021) also showed that smartphone apps can be used to monitor HRV in female professional cyclists during training camps. The series of studies supports the idea that physiological monitoring of female athletes should be inseparable from hormonal factors, stress, and training context.

In terms of anaerobic performance, the findings of this study are in line with the study of Wen et al. (2025), which stated that exercise performance in the menstrual cycle phase can be different through metabolic, neuromuscular, thermoregulated, and psychological mechanisms. Isenmann et al. (2024) also examined the influence of menstrual cycle phases on back squat performance, jumping ability, and women's psychological state based on performance level. Krishnan et al. (2025) reported the influence of menstrual cycle phases on shoulder agility and endurance in recreational basketball players, making it particularly relevant to the context of this study using the characteristics of game sports. In sports that require explosive activity, Bougrine et al. (2025) found that music-based warm-up strategies can improve anaerobic performance in female handball players, while Korkmaz et al. (2025) and Mor et al. (2025) emphasize that the anaerobic performance of female athletes is sensitive to certain interventions and physiological conditions. This supports the interpretation that vertical jump changes between phases are not a single phenomenon, but rather related to the neuromuscular readiness and biological condition of the athlete.

Findings related to neuromuscular stability and injury risk are also supported by previous research. Maruyama et al. (2022) reported that the menstrual cycle is related to changes in joint laxity in women, both athletes and non-athletes. Nédélec et al. (2021) emphasized the importance of paying attention to the phase of the menstrual cycle in the risk study of anterior cruciate ligament injury in female athletes. Duggan et al. (2022) also showed that the performance and risk of injury in female athletes in elite team sports are influenced by a variety of internal and external factors, including physiological and neuromuscular characteristics. Guthardt et al. (2026) through systematic review and meta-analysis also discussed the association of the menstrual cycle with muscle injury, which reinforces that biological phases need to be considered in the injury prevention system. Thus, the increase in the knee valgus indicator in certain phases in this study has a strong empirical foundation.

However, the literature also shows that the effect of the menstrual cycle on performance is not always consistent. Carmichael et al. (2021) in a narrative review emphasized that the results of research on menstrual cycle phases and the performance of female athletes still vary due to differences in design, test type, phase validation, and subject characteristics. Ekberg et al. (2024)

show that the effect of menstrual cycles on aerobic capacity in endurance-trained women is not always uniform. Niering et al. (2024), through systematic review and meta-analysis, also reported that the effect of menstrual cycle phase on maximum strength in healthy women still showed variation in results. Taylor et al. (2026) in the FENDURA project also highlighted that physiological and perceptual responses to both low- and high-intensity exercise can differ between individuals. Therefore, the results of this study need to be placed as empirical evidence supporting the importance of individual monitoring, not as a universal rule that all female athletes will respond to the cycle phase in the same pattern.

Contradictions in the literature can also be caused by methodological problems. Anckaert et al. (2021) emphasized the importance of monitoring the natural menstrual cycle using serum biomarkers such as estradiol, luteinizing hormone, and progesterone. Schlie et al. (2026) suggest that large-volume capillary blood sampling may be a valid alternative for assessing progesterone and 17β-estradiol in cycle phase identification in tactical female athletes. If the study relies solely on the menstrual calendar without hormonal validation, then the phase classification may be less accurate. Natalucci et al. (2026) even remind that menstrual symptoms, nutritional status, and hormonal contraceptives can be more meaningful than just naming the phases of the cycle. Thus, differences in results between studies can occur because some studies measure phases chronologically, while other studies emphasize biological validation and individual symptoms.

Another contradiction stems from the differences in sports and the type of demands of movement. Igonin et al. (2022) showed that the phases of the menstrual cycle can affect the movement patterns of female soccer players in competitive matches, while Yanez et al. (2026) found a relationship between the menstrual cycle and internal and external load in female CrossFit athletes. Both studies show that the impact of cycling can be different on endurance sports, game sports, strength sports, and high-intensity functional sports. Therefore, this study contributes because it combines aerobic performance indicators, anaerobic, dynamic stability, and biomechanical risk in the context of female athletes who require intermittent performance. This multidimensional approach helps bridge the differences in previous findings that often analyze performance variables separately.

Overall, previous research supports the main direction of this study's results, namely that the menstrual cycle phase is worth considering in performance monitoring and injury prevention. At the same time, the contradictions of some studies remind that the effects of the phases of the menstrual cycle should not be overgeneralized. Individual variation, exercise level, nutritional status, contraceptive use, stress, sleep quality, premenstrual symptoms, phase validation, and sports characteristics need to be considered. Thus, the contribution of this study not only shows the differences between phases but also strengthens the argument that the coaching of female athletes should be data-based, individual, and sensitive to biological factors.

Theoretically, the results of this study can be explained through the interaction between the endocrine system, cardiovascular system, neuromuscular system, metabolic system, and musculoskeletal system. The menstrual cycle involves changes in estrogen and progesterone levels that affect many bodily functions. Estrogen plays a role in vascular regulation, substrate metabolism, insulin sensitivity, mitochondrial function, muscle activation, as well as connective tissue characteristics. Progesterone plays a role in thermoregulation, ventilation response, basal body temperature, and fatigue perception. Wen et al. (2025) explain that changes in performance in the menstrual cycle phases can be mediated by metabolic, cardiopulmonary, neuromuscular, and psychological mechanisms. Nelson et al. (2025) also showed that the menstrual cycle can affect the mitochondrial respiration of human skeletal muscles. Therefore, changes in aerobic and anaerobic performance between phases in this study can be understood as the result of complex interactions between reproductive hormones and the body's energy system.

In the ovulation phase, increased estrogen can support the improvement of certain physiological functions. Cardiovascularly, estrogen is associated with increased vasodilation and regulation of blood flow, which can help transport oxygen to active muscles. Metabolically, hormonal changes can affect the use of carbohydrates and fats as energy substrates. MacGregor et al. (2023) showed that the phase of the menstrual cycle is related to metabolite changes in healthy women with regular cycles. Tagliapietra et al. (2024) also found that cyclical phases can influence physiological responses at rest and submaximal exercise. In the context of this study, the increase in aerobic capacity in certain phases can be interpreted because of improved oxygen transport efficiency, energy regulation, and cardiopulmonary readiness.

In the aspect of anaerobic performance, neuromuscular theory explains that the ability to generate power is influenced by the recruitment of motor units, the speed of nerve impulses, intermuscular coordination, tendon stiffness, and the ability of muscles to generate force in a short period of time. Isenmann et al. (2024) assert that the menstrual cycle phase can be associated with women's jumping ability and psychological state, while Niering et al. (2024) explain that the relationship between cycle phase and maximum strength still requires careful interpretation due to the variation in results between studies. The results of this study can be placed within this framework: certain phases appear to favor power output, but these responses are not always uniform and can be influenced by training status, neuromuscular adaptation, motivation, and perception of readiness.

On the dimension of neuromuscular stability, the theory of motor control states that the body maintains joint stability through the integration of proprioceptive information, muscle strength, reflex activation, and conscious motion control. The Y-Balance Test describes an athlete's ability to control the center of body mass while maintaining lower extremity stability. If proprioceptive control decreases, athletes may lose the quality of leg alignment while performing dynamic activities. Maruyama et al. (2022) show that the menstrual cycle may be related to changes in joint laxity. Soedirdjo et al. (2023) emphasize that sex hormones can be related to the dynamics of muscle activation and deactivation. These two findings support the interpretation that the decline in dynamic stability at a given phase may stem from combined changes in passive tissue and active neuromuscular control.

The knee valgus angle can be explained through the biomechanical theory of lower extremity injuries. Knee valgus occurs when the knee moves in the medial direction relative to the hip and ankle, especially during landing, cutting, or change of direction. Theoretically, a larger valgus can increase the load on the passive structure of the knee and increase the stress on the anterior cruciate ligament. Nédélec et al. (2021) and Guthardt et al. (2026) affirm that the risk of injury in female athletes needs to be seen in the relationship between hormonal, neuromuscular, and movement characteristics. Duggan et al. (2022) also explained that injuries in women's team sports are influenced by a combination of performance factors, training load, movement control, and biological factors. Thus, the increase in knee valgus angle in certain phases in this study can be understood as a sign that the active and passive stabilization systems of the knee are in a more vulnerable condition.

From the perspective of coaching science development, the results of this study support the shift from a general periodization approach to menstrual cycle-informed training. This approach does not mean that female athletes should be limited by the menstrual cycle but makes the cycle biological information to optimize training. Nagorna et al. (2026) show that hormonal monitoring and exercise strategies tailored to the menstrual cycle are beginning to become important directions in the development of women's performance in fitness and sports. Natalucci et al. (2026) added that symptoms, nutritional status, and hormonal contraceptives also need to be considered along with the cycle phases. Therefore, the developmental interpretation of this study is that the menstrual cycle should be positioned as one of the monitoring components, alongside HRV, sleep quality, RPE, pain status, nutritional status, and injury history.

Readiness theory or training readiness also needs to be developed. In conventional practice, an athlete's readiness is often seen from performance scores, ability to complete training sessions, or physical test results. The results of this study show that high performance is not always synonymous with safe motion readiness. In certain phases, athletes can have better aerobic capacity and power, but knee stability and alignment are more at risk. Therefore, the concept of readiness needs to be expanded to readiness for safe performance. This concept puts performance, neuromuscular control, biomechanics, recovery, and subjective conditions. Alecu et al. (2026) show that HRV and perceived recovery can be predictors of sprint athlete performance, while Madrigal-Cerezo et al. (2026) highlight the potential of wearable biosensing and machine learning for data-driven coaching support. These two research directions support the need for a more integrated evaluation system.

The next theoretical interpretation has to do with individualization. Variation in response between female athletes is very likely due to differences in cycle duration, hormone levels, menstrual symptoms, exercise level, biological age, sleep quality, energy availability, psychological status, and injury experience. Righi et al. (2022) showed that recreationally trained women can perceive the symptoms of the menstrual cycle differently and partially adjust the exercise based on phases. Helm et al. (2021) explain that nutritional interventions in the menstrual cycle phase can also affect athletic performance. This reinforces that this research should not be used to create rigid programs, but as a basis for the development of individual systems. Coaches need to recognize each athlete's pattern through repeated monitoring, not just applying general assumptions about menstrual phases.

Conceptually, this study expands the understanding of the relationship between performance and injury. In many training systems, performance and injury are often treated as two separate domains. In fact, high performance can increase mechanical load, while low stability can magnify the risk of injury when athletes move explosively. By integrating VO_2max, vertical jump, Y-Balance Test, and knee valgus angle, the study shows that performance and risk should be analyzed simultaneously. Her theoretical contribution is to strengthen a model of female athlete coaching that combines menstrual cycle physiology, autonomic monitoring, neuromuscular performance, and injury prevention biomechanics.

The main practical implication of this study is the need for coaches and sports practitioners to incorporate menstrual cycle monitoring into the coaching system of female athletes. This monitoring should not be carried out discriminatory, but as part of sports science support that aims to maintain the performance, health, and sustainability of athletes' careers. Nagorna et al. (2026) emphasized that hormonal monitoring and exercise strategies tailored to the menstrual cycle are important directions in improving women's performance. Righi et al. (2022) showed that women who actively practiced felt the symptoms of the menstrual cycle differently and partially adjusted the exercise based on phases. Natalucci et al. (2026) also emphasized that menstrual symptoms, nutritional status, and the use of hormonal contraceptives should be considered as they can affect the athlete's response. Therefore, coaches need to establish safe, professional, and trust-based communication so that athletes are comfortable reporting cycles, symptoms, pain, energy changes, and training readiness.

In exercise planning, the ovulation phase can be used as a potential phase for providing performance stimulus, especially exercises with higher aerobic and power demands. However, since this phase also shows greater indicators of biomechanical risk, high-intensity training needs to be combined with injury prevention protocols. Nédélec et al. (2021) emphasize the importance of paying attention to the phases of the menstrual cycle in the context of ACL injury risk, while Guthardt et al. (2026) emphasize that the relationship between the menstrual cycle and muscle injury needs to be a concern in the female injury prevention system. Maruyama et al. (2022) also showed changes in joint laxity during the menstrual cycle. On this basis, high-intensity sessions in the peak performance phase should begin with neuromuscular warm-ups, hip-knee-ankle stabilization exercises, proprioceptive exercises, hamstring and gluteal strengthening, and correction of landing and cutting techniques.

In the early menstrual or follicular phase, the coach needs to adjust based on the individual condition of the athlete. Not all athletes should lower the intensity of training in this phase, but symptoms such as pain, cramps, fatigue, dizziness, mood swings, or sleep disturbances need to be considered. Meng et al. (2022) showed that attitudes toward menstruation and cognitive-social stress can affect the autonomic nervous system in women with premenstrual syndrome. Kowalczyk et al. (2025) also report that anxiety, depression, and perseverative cognition may differ in women with natural cycles or contraceptive users. The findings suggest that the response to the menstrual cycle is not only physical, but also psychophysiological. Therefore, training strategies in this phase can be in the form of volume adjustments, moderate intensity, increased warm-up duration, active recovery, or exercise modification options according to the athlete's response.

In the luteal phase, the trainer needs to pay attention to the possibility of increased perception of fatigue, changes in body temperature, and decreased comfort in training. Taylor et al. (2026) highlight the importance of understanding the physiological and perceptual responses of female athletes to low- and high-intensity exercise in different phases of the cycle. Walker et al. (2025) also show that the cycle phase and measurement time can be related to stress markers such as salivary α-amylase and secretory immunoglobulin A. Thus, the luteal phase needs to be managed through more sensitive monitoring of the body's response. Exercises can be directed at technique maintenance, tactical drills, strengthening neuromuscular control, and active recovery. If the demands of the competition require high-intensity training, the trainer can use RPE, HRV, sleep quality, pain status, and mood as the basis for daily load adjustments.

The next practical implication is the importance of combining performance tests and injury risk tests in the evaluation of female athletes. Tests such as VO_2max and vertical jump are indeed important to know physical capacity. However, the results of this study show that performance tests are not enough if they are not accompanied by stability and movement quality analysis. The Y-Balance Test, landing observation, and knee valgus angle assessment need to be used to see if the athlete can perform safely. Duggan et al. (2022) emphasize that the performance and risk of injury in women's team sports are influenced by multidimensional factors. Başandaç et al. (2025) showed that progressive core stabilization exercises can affect the anaerobic performance of elite athletes, so stabilization exercises are not only useful for injury prevention but also have the potential to support performance. Thus, the exercise program should incorporate physical capacity enhancement and movement quality control.

For sports scientists and medical teams, the results of this study can be the basis for the preparation of injury screening protocols based on the phases of the menstrual cycle. Athletes who show an increase in knee valgus angle at certain phases need to be prioritized in the technique correction and injury prevention program. The program can include neuromuscular warm-up, posterior chain-based strength training, balance training, agility with frontal plane control, and landing mechanics education. Soedirdjo et al. (2023) emphasize the importance of understanding the relationship between sex hormones and the dynamics of muscle activation and deactivation. This suggests that motion analysis should not stop at external outcomes such as jump height, but also pay attention to activation patterns, contraction timing, and the body's ability to maintain joint alignment.

In the context of technology-based monitoring, this study supports the use of menstrual cycle recording applications, wearable devices, and HRV measurement as part of exercise decision-making. Javaloyes et al. (2021) showed that smartphone apps can be used to monitor HRV in female professional cyclists during training camps. Madrigal-Cerezo et al. (2026) highlight the potential of wearable biosensing and machine learning in supporting data-driven training. Alecu et al. (2026) report that HRV and perceived recovery can be predictors of performance in sprint athletes. By integrating data on menstrual cycles, HRV, sleep, RPE, and subjective complaints, trainers can make more accurate daily decisions than relying solely on visual observations or general exercise schedules.

In the context of coach education, this study shows the need to increase literacy about the physiology of female athletes. Coaches need to understand that menstruation is not a non-technical barrier, but a scientifically manageable biological variable. Carmichael et al. (2021) emphasized that there is still a gender data gap in sports research and practice, so women's training protocols should not only adopt models developed from male populations. Helm et al. (2021) also showed that nutritional interventions based on the phases of the menstrual cycle can be one approach to support performance. Therefore, the coach's education needs to include knowledge of the menstrual cycle, energy availability, premenstrual symptoms, hormonal contraception, ethical communication, and exercise adjustment strategies.

The broader implication of this study is the need to develop a more individualized and responsive model of exercise periodization. The model can integrate competition calendars, training phases, menstrual cycles, HRV data, sleep quality, fatigue perception, pain, nutrition, and neuromuscular test results. Schlie et al. (2026) point to the importance of cycle phase validation through progesterone and 17β-estradiol markers, while Anckaert et al. (2021) emphasize the use of serum biomarkers for natural cycle monitoring. In field practice, hormonal validation may not always be available, but the principle remains relevant: trainers need to collect more consistent, longitudinal, and individualized data. Thus, training decisions are not only based on the general calendar but also based on the actual response of the athlete.

Practically, the results of this study can be formulated into several recommendations. First, every team that fosters female athletes needs to have a system of recording menstrual cycles that is confidential, voluntary, and used for the purpose of training management. Second, the high-performance phase must be combined with injury prevention interventions, not just used for heavy training. Third, the evaluation of female athletes must be carried out in a multidimensional manner by combining physiological, anaerobic, neuromuscular, biomechanical, psychological, and subjective indicators. Fourth, coaches need to avoid overgeneralizing because each athlete's response to the menstrual cycle can be different. Thus, the results of this study make a real contribution to the development of sport science that is more sensitive to the biological needs of female athletes and more oriented towards safe, healthy, and sustainable performance.

CONCLUSION

This study concludes that the menstrual cycle phase is related to changes in physiological performance, anaerobic performance, neuromuscular stability, and biomechanical risk indicators in female athletes. These findings confirm that the menstrual cycle is not only a biological process, but also an important variable to consider in performance evaluation, training program formulation, and injury prevention strategies. The ovulation phase shows a tendency to be the phase with the highest physical performance, especially in aerobic capacity and leg power. This condition suggests that at certain phases female athletes can have better physiological readiness to perform high-intensity exercises, explosive movements, and sports activities that demand endurance and quick strength. However, such performance improvements are not always followed by improved biomechanical safety. In the same phase, neuromuscular stability tends to decrease, and the angle of the knee valgus increases, so the ovulation phase can be understood as a high-performance phase as well as a phase with a greater risk of injury. The early menstrual or follicular phase tends to show lower performance, while the luteal phase is in a transitional position with performance that is not as high as the ovulation phase but is relatively more neuromuscularly stable. This pattern shows that each phase of the menstrual cycle has different characteristics and cannot be simply generalized as a good or bad phase. Practically, the results of this study support the implementation of periodization of menstrual cycle-based exercise in an individual, ethical, and data-based manner. Coaches need to combine menstrual cycle monitoring with tests of athletes' performance, stability, movement quality, and subjective condition. With this approach, training programs can be structured more adaptively to optimize performance, reduce the risk of injury, and maintain the health and sustainability of female athletes' careers.

RECOMMENDATION

Based on the results of the study, coaches and sports practitioners are advised to include menstrual cycle monitoring as part of the evaluation and training planning system for female athletes. The monitoring needs to be carried out ethically, confidentially, voluntarily, and does not cause stigma for athletes. Information about cycle phases, menstrual symptoms, pain levels, sleep quality, fatigue, and exercise readiness can be used as a basis for adjusting the intensity, volume, and type of exercise given. In the ovulation phase, when physical performance tends to improve, trainers can take advantage of this phase for higher-intensity exercises, especially endurance, power, sprint, and explosive movement exercises. However, because this phase also shows an increase in biomechanical risk indicators, high-intensity training needs to be accompanied by an injury prevention program. Hip and knee stabilization exercises, hamstring and gluteal strengthening, dynamic balance exercises, proprioceptive, and landing techniques need to be given systematically to reduce the risk of knee valgus and lower extremity injuries. In the early menstrual or follicular phase, coaches are advised to be more flexible in managing the training load. Athletes who experience pain, cramps, fatigue, or discomfort should be given intensity adjustments, active recovery, or lighter weight technique exercises. Meanwhile, in the luteal phase, exercise can be directed at performance maintenance, strengthening neuromuscular control, recovery strategies, and fatigue management. For further studies, it is recommended to use a longitudinal design with a larger sample count, more accurate validation of menstrual cycle phases, and the addition of variables such as HRV, sleep quality, nutritional status, fatigue perception, and injury history. Further research also needs to be carried out on various sports so that menstrual cycle-based exercise recommendations can be developed more broadly and contextually.

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