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Menstrual Cycle Phase Influences Static Postural Control Under Single-Leg and Visual Deprivation Conditions

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Abstract

Anterior cruciate ligament (ACL) injuries are highly prevalent in sports and occur more frequently in female athletes, potentially due to hormonal influences across the menstrual cycle. This study aimed to analyze static postural control across menstrual cycle phases under varying postural and sensory demands. A longitudinal repeated-measures design was conducted in 22 healthy women (18–30 years) with regular menstrual cycles and moderate physical activity levels. Static balance was assessed using a Zebris pressure platform across three menstrual phases (follicular, ovulatory, luteal), three stance conditions (bipedal, dominant and non-dominant single-leg), and two visual conditions (eyes open and closed). Center of pressure variables included confidence area, velocity, and anteroposterior and mediolateral displacement. Differences between phases were analyzed using the Friedman test with Wilcoxon post hoc comparisons and Kendall's W effect size. No significant differences were observed in bipedal stance or under eyes-open conditions. However, under eyes-closed single-leg conditions, significant phase-dependent differences emerged. In dominant-leg stance, greater instability during the ovulatory phase was found for mediolateral displacement ($p < 0.001$; W = 0.321), anteroposterior displacement ($p = 0.007$; W = 0.223), confidence area ($p < 0.001$; W = 0.378), and velocity ($p = 0.048$; W = 0.138). Similar results were observed in the non-dominant leg for mediolateral displacement ($p = 0.03$; W = 0.159) and confidence area ($p = 0.002$; W = 0.287). These findings indicate that menstrual cycle phase influences postural control primarily under increased sensory and postural demands. The ovulatory phase appears to be associated with reduced stability when visual input is removed, suggesting a transient decrease in sensorimotor efficiency and a potential increase in neuromuscular vulnerability related to ACL injury risk.

Keywords: menstrual cycle; postural control; anterior cruciate ligament; injury risk

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1. Introduction

Anterior cruciate ligament (ACL) injury is one of the most frequent and severe knee injuries in the sports setting [1–4], with approximately 250,000 cases annually in the United

States [5] and an increasing incidence [6]. Female athletes present a 3- to 6-fold higher risk of ACL injury compared to males [4], reaching up to a tenfold increase depending on the sport modality [7]. This sex-related difference emerges after puberty, suggesting a possible hormonal influence [8]. Elevated estrogen concentrations have been associated with reduced mechanical strength of the ACL [8–10], and epidemiological evidence indicates a higher injury risk during the preovulatory phase of the menstrual cycle [11].

Neuromuscular and sensorimotor deficits, including impaired postural control, are considered risk factors for ACL injury [12]. Athletes who subsequently sustain this injury have shown alterations in neural connectivity in cortical and cerebellar regions involved in proprioception and balance [13]. Furthermore, the menstrual cycle phase has been associated with variations in neuromuscular performance, including reduced isometric knee strength during ovulation [14,15] and poorer postural balance in this phase [16].

Balance control requires the nervous system to integrate visual, vestibular, and somatosensory information [17–19] through sensory reweighting, whereby the brain determines the relative importance of each sensory channel depending on the context [20]. When the reliability of one or more senses decreases, the brain must rely more heavily on the remaining intact sensory systems to achieve stable balance [21]. As postural demands increase, such as during single-leg stance, reliance on visual information may also increase [19]. Likewise, it has been observed that increasing the difficulty of a balance task modulates dynamic postural control and reveals differences in sensorimotor control mechanisms [22]. On the other hand, the direction of attention also influences sensory weighting; an external attentional focus, oriented toward environmental stimuli, may reduce reliance on visual information for postural stabilization [18]. Assessing balance under eyes-closed conditions increases the sensory demands on the postural system and isolates the contribution of somatosensory and vestibular inputs, approximating situations in which vision is not specifically dedicated to maintaining static balance, such as in sports contexts where vision is primarily engaged in perceptual-motor skills such as hand–eye coordination, spatial perception, and rapid decision-making [23].

A recent systematic review on alterations in postural control throughout the menstrual cycle indicated that, although some studies have incorporated single-leg tasks or sensory manipulation, most assessments have been conducted in bipedal stance without visual restriction, lacking a systematic analysis of the interaction between cycle phase, task complexity, and visual availability [24].

In recent years, increasing attention has been directed toward understanding the influence of the menstrual cycle on neuromuscular performance, particularly in relation to injury risk and motor control. Hormonal fluctuations, especially in estrogen and progesterone levels, have been shown to influence not only ligament mechanical properties but also neuromuscular function and sensorimotor integration [25,26]. These hormonal variations may affect cortical excitability, motor unit recruitment, and intermuscular coordination, which are critical for maintaining postural stability under demanding conditions [25].

Moreover, postural control is a highly task-dependent ability, and its assessment under low-demand conditions may fail to detect subtle neuromuscular impairments. Recent evidence suggests that increased task complexity, such as single-leg stance or sensory deprivation, places greater demands on the sensorimotor system and enhances the sensitivity of balance assessments [22]. Under these conditions, deficits in neuromuscular control may become more evident, particularly when the central nervous system must rely more heavily on proprioceptive and vestibular inputs [17].

Despite these advances, the literature remains inconclusive regarding the extent to which menstrual cycle phases influence postural control. While some studies report phase-dependent variations in neuromuscular performance [24], others have failed to identify significant differences, highlighting the need for more comprehensive approaches that consider both task complexity and sensory conditions [27].

Therefore, the aim of the present study was to analyze static postural control across the phases of the menstrual cycle under bipedal and single-leg conditions, with eyes open and closed. It was hypothesized that differences between phases would be more evident under greater postural and sensory demands, particularly under eyes-closed and single-leg conditions.

2. Materials and Methods

2.1. Experimental Design

A longitudinal observational repeated-measures study was conducted in which static postural control was evaluated across different phases of the menstrual cycle (follicular, ovulatory, and luteal).

2.2. Subjects

A total of 22 healthy women with a mean age of 22.2 ± 3.2 years, mean body mass of 58.7 ± 9.2 kg, mean height of 164.2 ± 6.5 cm, and mean BMI of 21.7 ± 2.8 kg/m^2 and with regular menstrual cycles and a moderate level of physical activity according to World Health Organization classification were assessed. All participants had a natural menstrual cycle and did not use hormonal contraceptives. A cycle length of 21 to 35 days is considered indicative of a regular menstrual cycle; therefore, participants were asked about their previous cycles to include only those within this range [28]. Women aged 18–30 years were included to study a young adult population to reduce the potential influence of age-related reproductive, hormonal, or neuromuscular variability. Participants were considered healthy if they reported no vestibular disorders, no use of medication that could affect balance, no lower limb surgery within the previous year, and no lower limb injury at the time of assessment.

The study was approved by the Ethics Committee of Hospital Clínico San Carlos (reference number C.I. 24/418-E) and was conducted in accordance with the principles of the Declaration of Helsinki. All participants received a study information sheet and provided written informed consent prior to inclusion. All data were handled in strict confidence and in compliance with the European Regulation (EU) 2016/679 (General Data Protection Regulation) and the Spanish Organic Law 3/2018 of December 5 on Personal Data Protection and Guarantee of Digital Rights, as well as Law 14/2007 on Biomedical Research and its subsequent amendments, ensuring the confidentiality and anonymity of the data.

2.3. Measurements

Assessment sessions were individually scheduled to ensure accurate identification of each phase. Three measurement time points (sessions) were established: follicular phase (Session 1), ovulatory phase (Session 2), and luteal phase (Session 3). The follicular phase was defined as up to the fourth day of the cycle (from the onset of bleeding). Ovulation was estimated using commercial urinary luteinizing hormone (LH) test strips (MomMed Ovulation Test Strips, MomMed, Shenzhen, China; detection threshold: 25 mIU/mL), performed according to the manufacturer's instructions. Participants began LH testing individually between days 5 and 12 of the menstrual cycle. The test was performed at approximately the same time each day. Results were documented photographically and verified by the researchers. The ovulatory phase was defined as the 24-h period following a positive LH test result, and the luteal phase as 7 days after ovulation.

Balance was assessed using a Zebris PDM-L platform (Zebris Medical GmbH, Isny im Allgäu, Germany), with dimensions of 1370 mm × 535 mm × 15 mm (l × b × h) and a measurement area of 1220 mm × 474 mm (l × b). Participants performed 10-s trials under six experimental conditions: bipedal stance, dominant single-leg stance, and non-dominant single-leg stance, each under eyes-open and eyes-closed conditions (3 phases × 3 stance types × 2 visual conditions). Tests were performed barefoot, with arms alongside the body. Participants performed three trials for each condition following a familiarization procedure with the equipment. For each condition, the best value obtained across the three measurements was used for analysis. A one-minute rest interval was provided between measurements to minimize fatigue effects. Trials were considered invalid if the participant experienced a loss of balance or fall during testing; however, no falls or invalid trials were recorded during the assessments. The platform was calibrated before each participant began the assessment protocol according to the manufacturer's instructions. Foot placement and body position were standardized across all testing sessions and menstrual cycle phases. During bipedal stance, participants stood with both feet positioned within the platform area, oriented forward, placed hip-width apart, and with both knees extended. During single-leg stance, the supporting foot was positioned within the platform area and oriented forward, with the supporting knee kept extended, while the non-supporting limb was flexed at approximately 90° at the knee. In eyes-open conditions, participants fixed their gaze on a point approximately 2 m away. No visual feedback was provided. The protocol was like that used by Benito-Martínez et al. [29]. The same standardized instructions and positioning criteria were used before each trial.

Leg dominance was determined using the Harris Test of Lateral Dominance [30].

The studied variables derived from the center of pressure included confidence area (mm^2), calculated as an ellipse from the anteroposterior and mediolateral center of pressure displacements, velocity (mm/s), anteroposterior displacement (AP, mm), and mediolateral displacement (ML, mm), all of which were obtained directly from the Zebris PDM-L and softwareWinFDM-S v1.2.9.

2.4. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 29.0.1.1 software. Data normality was assessed using the Shapiro–Wilk test. Since several variables did not meet the assumption of normality, non-parametric analyses were performed.

Differences between menstrual cycle phases (follicular, ovulatory, and luteal) were assessed using the Friedman test within each stance condition (bipedal, dominant single-leg, and non-dominant single-leg) and visual condition (eyes open and eyes closed). When significant differences were observed, post hoc pairwise comparisons were conducted using the Wilcoxon signed-rank test with Bonferroni correction.

Effect size was estimated using Kendall's coefficient of concordance (W). Kendall's W was interpreted as follows: values < 0.10 were considered negligible, 0.10–0.29 small, 0.30–0.49 moderate, and ≥0.50 large effects. Statistical significance was set at $p \leq 0.05$. Given the multiple comparisons performed across variables and conditions, results with borderline significance values were interpreted with caution.

3. Results

Descriptive statistics (median and interquartile range) and Friedman test results are presented in Tables 1–3.

In bipedal stance, no significant differences between menstrual cycle phases were observed under any visual condition.

Table 1. Bipedal stance across menstrual cycle phases. Data are presented as median (Q1–Q3). Q1: first quartile; Q3: third quartile. Significant at $p \leq 0.05$ (Friedman test, Bonferroni-adjusted post hoc comparisons).

Bipedal Stance					
Visual Condition	**Variable**	**Follicular Median (Q1–Q3)**	**Ovulatory Median (Q1–Q3)**	**Luteal Median (Q1–Q3)**	***p***
Eyes open	ML displacement (mm)	3.35 (2.7–4.9)	3.5 (2.67–3.8)	3.65 (2.85–5.15)	0.205
	AP displacement (mm)	9.25 (6.87–11.57)	7.15 (5.5–10.9)	7.7 (6.0–12.25)	0.217
	Confidence area (mm^2)	22.25 (17.7–40.02)	19.85 (12.77–30.85)	24.05 (12.9–41.45)	0.483
	Velocity (mm/s)	5.45 (3.95–6.9)	4.9 (3.4–6.7)	5.7 (3.55–7.7)	0.783
Eyes closed	ML displacement (mm)	3.5 (2.08–6.0)	3.7 (2.5–5.3)	4.15 (3.27–4.6)	0.542
	AP displacement (mm)	8.55 (7.07–13.25)	9.7 (6.77–12.05)	7.6 (6.5–9.72)	0.109
	Confidence area (mm^2)	21.9 (13.27–59.15)	25.6 (17.1–45.47)	21.65 (18.62–33.35)	0.58
	Velocity (mm/s)	6.7 (5.17–8.7)	6.85 (5.42–10.2)	7.1 (4.5–8.42)	0.055

Table 2. Dominant leg across menstrual cycle phases. Data are presented as median (Q1–Q3). Q1: first quartile; Q3: third quartile. * Significant at $p \leq 0.05$ (Friedman test, Bonferroni-adjusted post hoc comparisons).

Dominant Single-Leg Stance							
Visual Condition	**Variable**	**Follicular Median (Q1–Q3)**	**Ovulatory Median (Q1–Q3)**	**Luteal Median (Q1–Q3)**	***p***	**Kendall's W**	**Post-Hoc**
Eyes open	ML displacement (mm)	7.80 (6.28–9.18)	8.10 (7.23–9.68)	8.15 (7.80–9.50)	0.077	0.117	-
	AP displacement (mm)	12.50 (11.60–17.08)	14.40 (10.25–16.80)	15.60 (12.13–18.60)	0.483	0.033	-
	Confidence area (mm^2)	84.50 (60.55–121.58)	91.00 (58.70–124.25)	100.10 (79.30–155.10)	0.403	0.041	-
	Velocity (mm/s)	20.40 (15.73–23.08)	18.05 (14.90–25.30)	18.30 (16.03–24.05)	0.496	0.032	-
Eyes closed	ML displacement (mm)	19.75 (16.85–22.60)	20.00 (16.65–25.63)	16.05 (14.65–19.50)	<0.001 *	0.321	1–2 (0.029 *) 1–3 (0.132) 2–3 (<0.001 *)
	AP displacement (mm)	26.35 (22.15–30.60)	27.50 (21.68–39.23)	24.05 (20.33–27.35)	0.007 *	0.223	1–2 (0.06) 1–3 (0.228) 2–3 (0.002 *)
	Confidence area (mm^2)	403.55 (290.05–566.23)	478.10 (292.83–749.25)	289.25 (229.63–504.30)	<0.001 *	0.378	1–2 (0.024 *) 1–3 (0.07) 2–3 (<0.001 *)
	Velocity (mm/s)	48.00 (39.38–66.05)	53.15 (38.38–72.08)	43.50 (39.98–57.00)	0.048 *	0.138	1–2 (0.451) 1–3 (0.097) 2–3 (0.016 *)

In dominant single-leg stance, no significant effects were detected under eyes-open conditions. However, under eyes-closed conditions, significant differences between phases were observed for mediolateral displacement ($p < 0.001$; W = 0.321), anteroposterior displacement ($p = 0.007$; W = 0.223), confidence area ($p < 0.001$; W = 0.378), and velocity ($p = 0.048$; W = 0.138). Post hoc analyses indicated greater instability in the ovulatory phase compared to the luteal phase, particularly in confidence area and mediolateral displacement.

In non-dominant single-leg stance, no significant differences were observed under eyes-open conditions. Under eyes-closed conditions, significant differences were detected for mediolateral displacement ($p = 0.03$; W = 0.159) and confidence area ($p = 0.002$; W = 0.287). Post hoc analyses indicated greater instability in the ovulatory phase compared to the luteal phase. In contrast, anterioposterior displacement and velocity did not show significant differences between menstrual-cycle phases.

Overall, differences between menstrual cycle phases emerged primarily under higher postural demand conditions, particularly during single-leg stance with visual deprivation.

Table 3. Non dominant leg across menstrual cycle phases. Data are presented as median (Q1–Q3). Q1: first quartile; Q3: third quartile. * Significant at $p \leq 0.05$ (Friedman test, Bonferroni-adjusted post hoc comparisons).

Non Dominant Single-Leg Stance							
Visual Condition	**Variable**	**Follicular Median (Q1–Q3)**	**Ovulatory Median (Q1–Q3)**	**Luteal Median (Q1–Q3)**	***p***	**Kendall's W**	**Post-Hoc**
Eyes open	ML displacement (mm)	8.00 (7.28–9.05)	8.95 (6.90–9.75)	7.55 (6.50–9.43)	0.658	0.019	-
	AP displacement (mm)	14.70 (11.58–16.55)	14.95 (11.28–17.35)	13.40 (11.48–16.13)	0.306	0.054	-
	Confidence area (mm^2)	92.80 (67.98–120.08)	112.10 (67.50–121.23)	80.50 (61.85–101.43)	0.639	0.020	-
	Velocity (mm/s)	16.40 (14.60–19.10)	19.15 (14.98–22.45)	18.20 (14.75–22.20)	0.562	0.026	-
Eyes closed	ML displacement (mm)	19.90 (15.00–22.70)	20.75 (18.48–24.40)	17.00 (15.43–18.93)	0.03 *	0.159	1–2 (0.407) 1–3 (0.083) 2–3 (0.01 *)
	AP displacement (mm)	26.30 (22.55–30.33)	28.70 (25.58–37.30)	24.25 (19.93–27.93)	0.058	0.129	-
	Confidence area (mm^2)	365.40 (306.13–543.90)	488.50 (357.48–719.08)	319.65 (253.78–409.48)	0.002 *	0.287	1–2 (0.016 *) 1–3 (0.291) 2–3 (<0.001 *)
	Velocity (mm/s)	52.95 (40.40–68.23)	53.50 (38.60–64.78)	45.15 (35.45–54.43)	0.075	0.118	-

4. Discussion

The results of the present study show a decline in static balance during the ovulatory phase under single-leg stance conditions with visual deprivation. However, no significant differences were observed in eyes-open conditions or during bipedal stance. Although a significant difference was observed for velocity during dominant single-leg stance with eyes closed ($p = 0.048$), this finding should be interpreted with caution given its borderline p value and the multiple comparisons performed across variables and conditions. This suggests that the postural system may compensate for subtle phase-associated alterations in postural control when sufficient sensory information is available; however, when visual input is removed and reliance on somatosensory and vestibular information increases, phase-associated differences in postural control may become more apparent under higher sensory demand. Previous evidence indicates that static balance tends to remain stable throughout the menstrual cycle, as recent studies have not found significant differences between phases in physically active women [31]. This discrepancy may be explained by the task-dependent nature of postural control, such that the use of more demanding conditions in our study (such as single-leg stance and absence of vision) may have increased sensitivity to detect subtle alterations. This suggests that the menstrual cycle may not affect overall performance but may influence neuromuscular control under higher postural demands.

The findings of the present study are consistent with emerging evidence suggesting that the effects of the menstrual cycle on neuromuscular performance are highly context-dependent. Recent research indicates that hormonal fluctuations may not uniformly affect motor output but rather influence the efficiency of sensorimotor integration, particularly under conditions of increased neuromuscular demand [32,33].

From a neurophysiological perspective, estrogen has been shown to modulate central nervous system function, including synaptic transmission and cortical excitability, which may influence motor control and coordination [34]. Additionally, fluctuations in hormone levels have been associated with alterations in proprioceptive acuity and joint position sense [35], which may contribute to increased postural sway observed during the ovulatory phase.

These findings are particularly relevant in the context of anterior cruciate ligament injury risk, as effective neuromuscular control is essential for maintaining knee stability

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during dynamic tasks. Even transient reductions in sensorimotor efficiency may increase susceptibility to injury, especially during high-demand activities such as landing or cutting maneuvers [36,37].

The greater postural sway observed during the ovulatory phase may be associated with menstrual-cycle phase-related changes in sensorimotor function; however, the absence of serum hormonal measurements prevents direct attribution to estrogen or progesterone concentrations. Authors such as Yim et al. [16] demonstrated greater postural sway during the ovulatory phase in young women with regular menstrual cycles. However, other authors, such as Reschechtko et al. [27], concluded that different phases of the menstrual cycle did not affect postural sway in women with natural cycles or those using contraceptives. These findings are not inconsistent with those of our study, as Reschechtko measured postural balance only under eyes-closed conditions but in a bipedal stance, a condition in which no significant differences were found in the present study either. Furthermore, the systematic review conducted by Pohle et al. [24] highlights the lack of consensus in the literature regarding the potential effects of progesterone on postural stability, confirming that changes in balance throughout the menstrual cycle remain unclear and require further investigation.

These findings suggest that visual input may compensate for subtle alterations in postural control and represent an important source of postural regulation under demanding balance conditions. When visual input is removed, greater postural sway may become apparent due to the increased reliance on somatosensory and vestibular information. Indeed, some studies have shown that the type of attentional focus, whether external or internal, can influence reliance on vision in postural control. An external attentional focus, directed toward movement outcomes rather than bodily sensations, is associated with reduced dependence on visual input for balance control [24].

The results of the present study suggest that postural control is not stable throughout the menstrual cycle, with a significant deterioration observed in a specific phase. This finding is particularly relevant in light of previous evidence identifying neuromuscular and sensorimotor deficits, including impaired postural control, as risk factors for ACL injury [12].

From a neurophysiological perspective, these phase-dependent alterations may reflect transient changes in central processing, as previous studies have described altered functional connectivity in cortical and cerebellar regions involved in proprioception and motor control in athletes who subsequently sustain ACL injuries [13].

Therefore, the reduction in postural stability observed during this phase may represent a period of increased vulnerability, potentially contributing to a higher injury risk through decreased efficiency in sensorimotor integration and motor control.

Our study supports the notion that task difficulty acts as a modulator of the effects associated with the menstrual cycle; thus, significant differences were observed only in the most challenging conditions, namely single-leg stance with eyes closed. This is consistent with the findings of Muehlbauer et al. [22], who demonstrated that increased task difficulty entails greater involvement of the neuromuscular control system.

Finally, the results suggest the need to consider the menstrual cycle as a relevant variable in training planning, adjusting load and task complexity according to the phase, particularly during the ovulatory phase. In this regard, it may be advisable to reduce exposure to tasks that require high neuromuscular control or involve potentially risky situations, such as changes of direction or landing maneuvers during this phase [38]. Likewise, these findings reinforce the importance of implementing neuromuscular and proprioceptive training programs aimed at improving sensorimotor integration, including progressions that involve reduced visual input to enhance proprioceptive function [39].

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From a preventive perspective, identifying phases of increased vulnerability may contribute to optimizing injury prevention strategies. Overall, these results support the need for an individualized, evidence-based approach that integrates hormonal factors into the design of training and injury prevention programs for female athletes.

5. Conclusions

Women experience altered balance performance during the ovulatory phase of the menstrual cycle under conditions of increased proprioceptive demand. These findings suggest phase-associated differences in static postural control, particularly under monopodal and visual deprivation conditions, although their direct relationship with ACL injury risk requires further investigation.

6. Limitations and Future Lines of Research

The study included 22 participants. Although statistically significant differences were detected, the sample size can be considered small, which requires cautious interpretation of the physiological implications.

Identification of menstrual cycle phases was performed using urinary luteinizing hormone (LH) test strips. Blood analyses were not conducted; therefore, direct and precise measurement of hormonal concentrations at the exact time of testing was not available.

Assessments focused exclusively on static balance using a pressure platform. The study did not include dynamic tasks (such as jumping or changes of direction), which may be more representative of real injury-risk situations in sports contexts.

In addition, relatively short trial durations (10 s) were used during postural-control assessment. Although this approach reduced fatigue and allowed repeated testing across multiple conditions, shorter center of pressure recordings may increase measurement variability compared with longer-duration protocols.

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