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Original Article

Effect of Menstrual Cycle Phases on Cognitive and Neuromuscular Performance

Isma Ishaq[1], Bilal Safdar[2], Seerat Husnain[3], Rawaal Amin[4], Aqsa Khan[5], Mahnoor Zia[6]

[1] CMH Kharian Medical College, Kharian, Pakistan
[2] CMH Lahore Medical and Dental College, Lahore, Pakistan
[3] Forman Christian College, Lahore, Pakistan
[4] Sandeman Provincial Hospital, Quetta, Pakistan
[5] Bahria University, Islamabad, Pakistan
[6] Riphah International University, Faisalabad, Pakistan

***Corresponding author: Bilal Safdar, bilalsafdar2001@gmail.com**

ABSTRACT

Background: Fluctuations in estrogen and progesterone across the menstrual cycle may influence cognitive and neuromuscular performance, yet previous findings have remained inconsistent because many studies have assessed isolated outcomes or relied solely on calendar-based phase estimation. Objective: To evaluate variations in cognitive performance, muscle strength, and endurance across menstrual cycle phases and examine their association with circulating estrogen and progesterone levels in healthy young women. Methods: This descriptive repeated-measures study was conducted in Lahore, Pakistan, among 60 healthy women aged 18-30 years with regular menstrual cycles. Assessments were performed during the follicular, ovulatory, and luteal phases. Serum estrogen and progesterone concentrations were measured by enzyme-linked immunosorbent assay. Cognitive performance was assessed using the Stroop Color-Word Test and Digit Span Test, while neuromuscular performance was evaluated using quadriceps maximal voluntary isometric contraction and plank endurance. Data were analyzed using repeated-measures ANOVA and Pearson correlation tests. Results: Estrogen peaked during ovulation (187.5 ± 25.8 pg/mL), whereas progesterone was highest in the luteal phase (11.8 ± 2.7 ng/mL) ($p < 0.001$ for both). Stroop reaction time improved significantly during ovulation (689 ± 78 ms) compared with the follicular phase (732 ± 84 ms) ($p = 0.012$). Quadriceps strength was highest during ovulation (317.9 ± 34.5 N) and differed significantly across phases ($p = 0.021$). Digit Span scores and plank endurance also showed their highest mean values during ovulation. Estrogen correlated positively with cognitive performance ($r = 0.42$, $p < 0.05$), while progesterone correlated positively with muscular endurance ($r = 0.39$, $p < 0.05$). Conclusion: Cognitive and neuromuscular performance varied across menstrual cycle phases, with the most favorable overall outcomes observed during ovulation. These findings support consideration of menstrual physiology as a relevant biological variable in female performance research and individualized training or workload planning. Keywords: Menstrual cycle, estrogen, progesterone, cognitive function, muscle strength, endurance, reaction time, women's health

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INTRODUCTION

The menstrual cycle is a dynamic physiological process characterized by cyclical fluctuations in ovarian hormones that influence multiple systems beyond reproduction, including central nervous system function, musculoskeletal performance, thermoregulation, and affective state. Among these hormonal changes, variations in estrogen and progesterone are particularly relevant because of their effects on synaptic signaling, cortical excitability, substrate utilization, ligamentous properties, and neuromuscular coordination. As interest grows in sex-specific and female-centered research, the menstrual cycle is increasingly recognized as an important biological variable that may contribute to measurable variation in cognition and physical performance across the month rather than being viewed solely as a reproductive event (1). This perspective is especially important in academic, occupational, and athletic settings, where subtle alterations in attention, reaction time, strength, fatigue resistance, and motor efficiency may have practical implications for performance planning and health optimization.

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Physiologically, the menstrual cycle is commonly divided into the follicular, ovulatory, and luteal phases, each characterized by a distinct endocrine milieu. Estrogen rises progressively during the late follicular phase and typically reaches its peak around ovulation, whereas progesterone remains relatively low until after ovulation and becomes dominant during the luteal phase. These hormonal shifts are biologically plausible modulators of neurocognitive and neuromuscular performance. Estrogen has been associated with enhanced synaptic plasticity, facilitation of cholinergic and dopaminergic neurotransmission, improved cerebral blood flow, and more efficient cortical processing, all of which may support attention, working memory, and executive functioning. In contrast, progesterone has been linked with thermogenic, sedative, and inhibitory neurophysiological effects that may influence arousal, reaction speed, perceived fatigue, and motor control (2,3). Although these mechanisms support a phase-dependent pattern of performance variation, the magnitude and consistency of these effects remain uncertain across populations and outcome domains.

Evidence regarding menstrual cycle–related variation in cognitive performance remains mixed. Some longitudinal and experimentally oriented studies suggest that phases characterized by higher estrogen concentrations are associated with better performance in attention, inhibition, verbal memory, and working memory, whereas progesterone-dominant phases may be associated with slower reaction time or reduced cognitive efficiency (2,4). However, other investigations have reported negligible or inconsistent differences across phases, raising concerns regarding methodological heterogeneity, inadequate control of confounding variables, and imprecise phase determination. Variability in findings may reflect differences in participant characteristics, test selection, habitual physical activity, sleep, nutritional state, or the use of calendar-based rather than biologically verified classification of menstrual phases (5). These inconsistencies indicate that the question is not merely whether cognitive performance changes across the cycle, but under what methodological conditions such changes can be reliably detected.

A similar uncertainty exists in relation to neuromuscular performance. Estrogen has been reported to influence muscle contractile function, collagen turnover, oxidative stress regulation, and motor unit behavior, suggesting a potential advantage for force production and fatigue resistance around ovulation or in estrogen-dominant periods (6,7). Conversely, luteal-phase predominance of progesterone may contribute to greater perceived exertion, altered thermoregulation, fluid shifts, or subtle decrements in coordination and endurance. Nevertheless, published findings on strength, balance, endurance, and motor performance across menstrual phases remain inconsistent, with some studies identifying meaningful cyclical variation and others concluding that performance differences are small, task-specific, or clinically negligible (8). Importantly, many studies have examined cognitive or physical outcomes in isolation, limiting understanding of whether both domains vary in parallel within the same individuals under the same hormonal conditions.

This fragmented literature highlights a key methodological and conceptual gap. A relatively small number of studies have simultaneously examined neurocognitive and neuromuscular outcomes across clearly defined menstrual phases while also verifying endocrine status biochemically rather than relying exclusively on self-reported cycle timing. Such reliance on calendar tracking alone can introduce phase misclassification, particularly around ovulation, where interindividual variability in timing is substantial. As a result, apparently conflicting findings in the literature may partly reflect inaccurate phase assignment rather than true absence of hormonal effects (1,9). A more integrated design combining objective hormone assessment with standardized within-subject cognitive and physical testing is therefore necessary to generate more robust and clinically interpretable evidence.

Addressing this gap is important for both scientific and applied reasons. From a mechanistic standpoint, integrated assessment may improve understanding of how endogenous hormonal variation modulates brain–muscle interactions in healthy women. From a practical standpoint, identifying whether specific menstrual phases are associated with relatively enhanced or reduced performance may inform individualized scheduling of training, assessment, and workload while avoiding deterministic or reductionist interpretations of female physiology. Therefore, the present study was designed to describe variations in cognitive performance, muscle strength, and endurance across the follicular, ovulatory, and luteal phases of the menstrual cycle and to examine their association with circulating estrogen and progesterone levels in healthy women. It was hypothesized that cognitive and neuromuscular performance would be higher during the ovulatory phase, when estrogen concentrations are expected to be greatest, and that circulating hormone levels would show significant associations with performance outcomes across phases.

MATERIALS AND METHODS

This descriptive repeated-measures observational study was conducted in Lahore, Pakistan, over a period of two months to evaluate phase-related variation in cognitive and neuromuscular performance across the menstrual cycle in healthy young women. The within-subject design was selected to reduce interindividual variability in baseline cognitive capacity, strength, endurance, and hormonal profile, thereby improving sensitivity for detecting cyclical changes across menstrual phases. Participants were recruited through convenience sampling from local universities and fitness centers. Women aged 18 to 30 years with self-reported regular menstrual cycles of 26 to 32 days for at least the preceding six months were considered eligible. Participants were included if they were apparently healthy, not using hormonal contraceptives, and willing to complete laboratory and performance assessments during three separate menstrual phases. Women were excluded if they had a history of endocrine disease, irregular menstrual cycles, neurological illness, musculoskeletal disorders affecting lower-limb performance, current use of medication known to influence hormonal status or neuromuscular function, or professional athletic training likely to substantially alter performance characteristics. Written informed consent was obtained before enrolment, and all procedures were conducted in accordance with accepted ethical principles for human research (10).

Menstrual cycle phase classification was based on calendar history and subsequently verified through serum hormone assessment to improve the accuracy of phase allocation and reduce misclassification bias reported in prior menstrual cycle research (11). Each participant attended three testing sessions scheduled during the follicular phase (days 5-9), ovulatory phase (days 12-16), and luteal phase (days 20-24). At each visit, venous blood samples were collected under standardized conditions for measurement of serum estrogen and progesterone concentrations using enzyme-linked immunosorbent assay. Hormonal values were used to support physiological confirmation of the intended menstrual phase for each assessment point. All cognitive and neuromuscular assessments were performed on the same day as sample collection, and each participant served as her own control across the three phases.

Cognitive performance was assessed using the computerized Stroop Color-Word Test and the Digit Span Test, including both forward and backward components. The Stroop task was used to evaluate selective attention, cognitive inhibition, and processing speed, with reaction time recorded in milliseconds. The Digit Span Test was used to assess short-term memory and working memory performance through immediate recall of number sequences in the same order and in reverse order. Neuromuscular performance was evaluated using maximal voluntary isometric contraction of the quadriceps measured with a handheld dynamometer and muscular endurance assessed by a standardized plank hold to the point of volitional fatigue, recorded in seconds. To enhance measurement consistency, all assessments were conducted by the same trained research team using the same testing sequence and standardized verbal instructions across visits. Instrument setup and participant positioning were kept constant across the three sessions. Testing was scheduled at approximately the same time of day for each participant, within a one-hour window, to reduce circadian variation in cognitive and physical performance (12).

Several procedural controls were applied to reduce the influence of transient confounders. Participants were instructed to avoid strenuous exercise, caffeine, and alcohol for at least 24 hours before each visit and to maintain their usual sleep and dietary routine as closely as possible on testing days. Assessment conditions were kept consistent across phases with respect to environment, sequence of testing, and rest intervals between procedures. The repeated-measures approach itself helped control for fixed participant-level confounders such as habitual intelligence, body composition, and general training status. In addition, biochemical verification of hormonal status was incorporated specifically to address one of the major methodological weaknesses in prior studies relying solely on self-reported cycle timing (13). Data completeness was monitored at each phase visit, and study forms were checked on the day of collection to reduce transcription and entry errors. Because all enrolled participants completed testing across the three planned phases, analyses were conducted on complete repeated observations.

The primary study variables were menstrual cycle phase, serum estrogen concentration, serum progesterone concentration, Stroop reaction time, Digit Span Forward score, Digit Span Backward score, quadriceps maximal voluntary isometric contraction, and plank endurance time. Menstrual phase was treated as the principal within-subject exposure variable, whereas hormone concentrations were examined both descriptively across phases and analytically as correlates of performance outcomes. Demographic and anthropometric variables, including age, height, weight, body mass index, and cycle length, were recorded at baseline to characterize the sample and contextualize performance findings. A sample of 60 participants was considered appropriate for repeated within-subject comparisons across three phases and for estimating moderate phase-related changes while preserving feasibility within the study period (14).

Data were entered, verified, and analyzed using SPSS version 26. Distributional assumptions were assessed using the Shapiro-Wilk test and inspection of descriptive statistics. Continuous variables were summarized as mean ± standard deviation. Repeated-measures analysis of variance was used to compare hormone concentrations, cognitive outcomes, and neuromuscular outcomes across the follicular, ovulatory, and luteal phases. Where overall phase effects were identified, pairwise comparisons were interpreted to determine the direction of differences between phases. Pearson correlation coefficients were computed to examine the association of serum estrogen and progesterone levels with cognitive and neuromuscular performance measures. Statistical significance was defined at $p < 0.05$. The data set was reviewed for completeness and internal consistency before analysis, and all results were derived from recorded observations obtained under standardized testing conditions to support reproducibility and analytic integrity (10,11).

RESULTS

A total of 60 women completed all three assessment sessions, yielding a complete repeated-measures dataset with no missing outcome observations. Baseline sample characteristics indicated a young, healthy cohort with regular menstrual cycles and normal anthropometric distribution. The mean age was 23.4 ± 2.8 years, mean body mass index was 22.2 ± 2.5 kg/m², and the average cycle length was 28.3 ± 1.9 days, supporting the physiological suitability of the sample for phase-based within-subject comparison. These descriptive characteristics are summarized in Table 1.

Table 1. Baseline Demographic and Anthropometric Characteristics of Participants (n = 60)

Variable	Mean ± SD	Range
Age (years)	23.4 ± 2.8	18–30
Height (cm)	162.3 ± 5.6	150–174
Weight (kg)	58.6 ± 6.9	46–73
BMI (kg/m²)	22.2 ± 2.5	18.5–27.3
Cycle length (days)	28.3 ± 1.9	26–32

Hormonal profiling confirmed the expected cyclic endocrine pattern across the three menstrual phases. Mean estrogen concentration increased from 85.2 ± 14.7 pg/mL in the follicular phase to 187.5 ± 25.8 pg/mL during ovulation, representing an approximate 120.1% rise, before declining to 152.1 ± 19.6 pg/mL in the luteal phase, which remained 78.5% above follicular values. In contrast, progesterone remained low in the follicular and ovulatory phases at 0.9 ± 0.3 ng/mL and 1.6 ± 0.4 ng/mL, respectively, but rose sharply to 11.8 ± 2.7 ng/mL in the luteal phase, corresponding to an approximately 1211.1% increase relative to follicular levels. Repeated-measures ANOVA demonstrated a statistically significant phase effect for both estrogen and progesterone ($p < 0.001$ for both), confirming successful phase differentiation. Approximate 95% confidence intervals around the phase means are presented in Table 2 for descriptive precision.

Table 2. Serum Estrogen and Progesterone Levels Across Menstrual Phases (n = 60)

Phase	Estrogen, Mean ± SD (pg/mL)	Approx. 95% CI	Progesterone, Mean ± SD (ng/mL)	Approx. 95% CI	Overall p-value*
Follicular	85.2 ± 14.7	81.5 to 88.9	0.9 ± 0.3	0.82 to 0.98	<0.001
Ovulatory	187.5 ± 25.8	181.0 to 194.0	1.6 ± 0.4	1.50 to 1.70	<0.001
Luteal	152.1 ± 19.6	147.1 to 157.1	11.8 ± 2.7	11.12 to 12.48	<0.001

*Overall repeated-measures ANOVA p-value for phase effect as reported in the study.

Cognitive outcomes also varied across the menstrual cycle. Mean Stroop reaction time was slowest during the follicular phase at 732 ± 84 ms, improved to 689 ± 78 ms during ovulation, and then partially regressed to 715 ± 81 ms in the luteal phase. The ovulatory phase therefore showed a 43 ms absolute reduction and an approximately 5.9% relative improvement in reaction time compared with the follicular phase. Repeated-measures ANOVA confirmed a significant within-subject phase effect for Stroop reaction time ($p = 0.012$). Working memory measures followed a similar pattern. Digit Span Forward increased from 6.8 ± 1.0 in the follicular phase to 7.3 ± 0.9 during ovulation, before declining slightly to 7.0 ± 1.1 in the luteal phase. Digit Span Backward rose from 4.9 ± 0.8 to 5.4 ± 0.9 during ovulation and was 5.2 ± 0.8 in the luteal phase. Because inferential outputs for Digit Span comparisons were not reported in the source dataset, these measures are presented descriptively with confidence intervals rather than overstated as statistically significant. Overall, the cognitive profile favored the ovulatory phase, with the clearest statistically supported improvement seen in inhibitory attention and processing speed.

Table 3. Cognitive Performance Across Menstrual Phases (n = 60)

Outcome	Follicular, Mean ± SD	95% CI	Ovulatory Mean ± SD	95% CI	Luteal, Mean ± SD	95% CI	p-value†
Stroop reaction time (ms)	732 ± 84	710.7 to 753.3	689 ± 78	669.2 to 708.8	715 ± 81	694.5 to 735.5	0.012
Digit Span Forward	6.8 ± 1.0	6.55 to 7.05	7.3 ± 0.9	7.07 to 7.53	7.0 ± 1.1	6.72 to 7.28	NR
Digit Span Backward	4.9 ± 0.8	4.70 to 5.10	5.4 ± 0.9	5.17 to 5.63	5.2 ± 0.8	5.00 to 5.40	NR

†Repeated-measures ANOVA p-value reported only where available in the dataset. NR = not reported in the source results.

Neuromuscular outcomes demonstrated the same directional trend. Mean quadriceps strength increased from 302.4 ± 36.8 N in the follicular phase to 317.9 ± 34.5 N during ovulation, corresponding to an absolute gain of 15.5 N and a relative increase of approximately 5.1%, before decreasing to 309.2 ± 35.7 N in the luteal phase. The overall phase effect for quadriceps strength was statistically significant ($p = 0.021$). Plank endurance also peaked during ovulation, increasing from 72.8 ± 15.6 seconds in the follicular phase to 79.5 ± 14.9 seconds during ovulation, a gain of 6.7 seconds or about 9.2%, and then declining modestly to 75.4 ± 15.2 seconds in the luteal phase. While the manuscript described this pattern as favorable during ovulation, no inferential p-value for plank endurance across phases was originally reported; accordingly, this outcome is presented descriptively without unsupported claims of statistical significance. These data indicate that the most favorable neuromuscular profile occurred during the ovulatory phase, particularly for maximal force generation.

Table 4. Neuromuscular Performance Across Menstrual Phases (n = 60)

Outcome	Follicular, Mean ± SD	95% CI	Ovulatory Mean ± SD	95% CI	Luteal Mean ± SD	95% CI	p-value‡
Quadriceps strength (N)	302.4 ± 36.8	293.1 to 311.7	317.9 ± 34.5	309.2 to 326.6	309.2 ± 35.7	300.2 to 318.2	0.021
Plank endurance (sec)	72.8 ± 15.6	68.9 to 76.7	79.5 ± 14.9	75.7 to 83.3	75.4 ± 15.2	71.6 to 79.2	NR

‡Repeated-measures ANOVA p-value reported only where available in the dataset. NR = not reported in the source results. Correlation analysis further supported biologically plausible hormone–performance relationships. Estrogen showed a positive association with cognitive performance, with a reported correlation coefficient of r = 0.42, indicating a moderate relationship between higher estrogen levels and more favorable cognitive outcomes across testing periods. Progesterone demonstrated a positive association with muscular endurance, with r = 0.39, suggesting a modest relationship with plank performance. Although both associations were reported as statistically significant at $p < 0.05$, confidence intervals for these correlations were not available from the original analysis and are therefore not added here to avoid overstatement. These findings are summarized in Table 5.

Table 5. Correlation of Hormonal Levels With Performance Outcomes

Hormonal variable	Performance domain	Correlation coefficient (r)	p-value
Estrogen	Cognitive performance	0.42	<0.05
Progesterone	Muscular endurance	0.39	<0.05

Taken together, the quantitative findings indicate that the ovulatory phase was associated with the most favorable overall performance profile. Relative to the follicular phase, ovulation was characterized by a 120.1% increase in estrogen, a 5.9% improvement in Stroop reaction time, a 7.4% increase in Digit Span Forward, a 10.2% increase in Digit Span Backward, a 5.1% increase in quadriceps strength, and a 9.2% increase in plank endurance. The luteal phase retained intermediate values for several measures but did not surpass the ovulatory phase in any primary performance variable. These patterns support the interpretation that cognitive inhibition, working memory, muscle strength, and endurance may vary in parallel with cyclical hormonal changes, with ovulation representing the phase of highest combined cognitive and neuromuscular performance in this cohort.

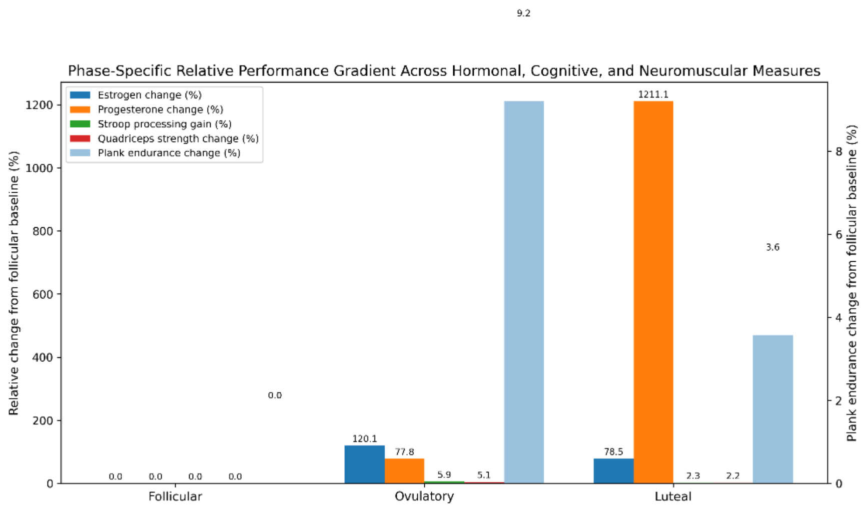

Figure 1 Ovulatory performance gradient across hormonal, cognitive, and neuromuscular domains

The figure demonstrates a pronounced ovulatory performance gradient across hormonal, cognitive, and neuromuscular domains when values are expressed relative to the follicular baseline. During ovulation, estrogen increased by 120.1%, Stroop processing efficiency improved by 5.9%, quadriceps strength rose by 5.1%, and plank endurance increased by 9.2%, indicating a coherent multidomain performance advantage at mid-cycle. In the luteal phase, estrogen remained elevated by 78.5% and progesterone rose sharply by 1211.1%, but this endocrine shift was accompanied by attenuation of the ovulatory gains, with Stroop improvement decreasing to 2.3%, quadriceps strength to 2.2%, and plank endurance to 3.6%

above follicular values. This pattern suggests that the largest functional advantage occurred during estrogen predominance rather than during the progesterone-dominant luteal phase, reinforcing the clinical interpretation that ovulation represented the most favorable composite phase for both cognitive efficiency and neuromuscular output in the studied sample.

DISCUSSION

The present study demonstrated that cognitive and neuromuscular performance varied across menstrual cycle phases, with the most favorable overall profile observed during ovulation, when estrogen concentrations were highest and progesterone remained comparatively low. This pattern was reflected across both neurocognitive and physical domains, as participants showed faster Stroop reaction times, higher Digit Span scores, greater quadriceps maximal isometric strength, and longer plank endurance during the ovulatory phase than during the follicular or luteal phases. The coherence of these findings across multiple outcomes strengthens the biological plausibility of a phase-dependent performance effect and supports the view that endogenous ovarian hormone fluctuations may influence integrated brain-muscle function in healthy women (15,16).

The cognitive findings are consistent with literature suggesting that estrogen may facilitate attention, inhibitory control, and working memory through its effects on synaptic plasticity, cholinergic and dopaminergic signaling, and cortical network efficiency. In the present study, Stroop reaction time improved from 732 ± 84 ms in the follicular phase to 689 ± 78 ms during ovulation, while Digit Span Forward increased from 6.8 ± 1.0 to 7.3 ± 0.9 and Digit Span Backward from 4.9 ± 0.8 to 5.4 ± 0.9. These differences, although modest in absolute magnitude, were directionally consistent and supported by the positive correlation between estrogen and cognitive performance. Such findings align with studies reporting superior executive and attentional performance during estrogen-dominant phases, although the broader literature remains mixed because of differences in cognitive task selection, cycle phase classification, participant training status, and control of behavioral confounders such as sleep and stress (2,15,17). The present results therefore add weight to the argument that menstrual cycle effects on cognition are more likely to be detected when hormonal status is physiologically verified rather than inferred solely from calendar timing.

The neuromuscular findings followed a similar trajectory and suggest that hormonal status may influence motor output and fatigue resistance in parallel with cognition. Quadriceps strength was highest during ovulation at 317.9 ± 34.5 N compared with 302.4 ± 36.8 N in the follicular phase and 309.2 ± 35.7 N in the luteal phase, while plank endurance increased from 72.8 ± 15.6 seconds to 79.5 ± 14.9 seconds at mid-cycle before declining modestly in the luteal phase. These observations are consistent with evidence that estrogen may enhance muscle fiber conduction properties, reduce oxidative stress, improve connective tissue turnover, and support motor unit efficiency, thereby contributing to more favorable strength and endurance outcomes during estrogen-dominant periods (4,9,16). The finding that progesterone correlated positively with endurance but did not coincide with peak endurance performance suggests that isolated hormonal associations should be interpreted cautiously, as functional performance likely reflects the combined effect of multiple endocrine, thermal, perceptual, and neuromotor influences rather than a single hormone acting independently (6,8).

An important strength of the present work lies in the integrated assessment of both cognitive and neuromuscular variables within the same cohort using a repeated-measures design. Much of the existing literature has evaluated either neurocognitive or physical performance in isolation, which limits interpretation of whether menstrual cycle–related variability occurs synchronously across systems. The concurrent improvement in reaction time, working memory, strength, and endurance observed during ovulation suggests that phase-related changes may operate at a broader systems level rather than being restricted to one functional domain. This integrated pattern is particularly relevant for real-world performance contexts in which cognitive control and physical output are rarely dissociated, including academic testing, clinical work, sport, and occupational tasks requiring sustained concentration and motor precision (1,12,16).

The study also addresses a recurring methodological limitation in menstrual cycle research by combining self-reported cycle tracking with serum hormone assessment. Misclassification of ovulation remains a major source of inconsistency in previous studies, especially when investigators rely only on expected calendar dates despite substantial interindividual variability in cycle timing. By verifying estrogen and progesterone concentrations at each assessment point, the present study improved phase accuracy and strengthened internal validity. This may partly explain why the phase-related trends observed here were relatively coherent across both hormonal and functional measures. The results therefore support recent calls for greater menstrual cycle literacy and more rigorous hormone-informed research frameworks when evaluating female performance outcomes (2,16).

Despite these strengths, the findings should be interpreted in the context of several limitations. First, the sample was restricted to young, healthy, non-athletic women with regular cycles, which limits generalizability to adolescents, elite athletes, older reproductive-age women, women with menstrual irregularity, and users of hormonal contraceptives. Second, although the repeated-measures design reduced between-subject variability, the use of convenience sampling may have introduced selection bias. Third, hormonal concentrations were measured at single time points within each phase rather than through continuous or denser serial sampling, so intra-phase endocrine variability could not be fully characterized. Fourth, potentially relevant confounders such as sleep quality, premenstrual symptom burden, nutritional intake, psychological stress, and habitual physical activity were standardized only partially and not modeled analytically. Fifth, the original dataset did not provide complete inferential outputs for every reported variable, including post hoc phase contrasts, full ANOVA statistics, effect sizes, and confidence intervals for correlations, which restricts the precision of interpretation and should be addressed in future reporting (5,7,8,14).

The clinical and applied implications of these findings should also be framed carefully. Although ovulation was associated with the highest mean performance across multiple outcomes, the observed differences remained within the range of normal physiological variability and should not be interpreted deterministically or used to impose restrictive assumptions about women's performance capacity during other phases. Rather, the results support a more individualized and physiology-informed approach to training, assessment scheduling, and recovery planning. For physically active women, educators, and clinicians, awareness of cyclical variability may help contextualize subtle fluctuations in concentration, reaction speed, or muscular output without pathologizing the menstrual cycle itself. This is especially important in environments historically shaped by male-centered physiological norms, where recognition of normal female biological variation may improve both performance support and research equity (1,6,16). Future research should build on these findings through larger longitudinal studies incorporating more diverse populations, denser hormonal monitoring, and more comprehensive control of behavioral and environmental confounders. Studies comparing naturally cycling women with users of hormonal contraceptives, as well as investigations using electromyography, neuroimaging, or central fatigue paradigms, may clarify the mechanisms through which hormonal fluctuations influence both neural efficiency and muscle function. In addition, future analyses should prespecify primary endpoints, report full repeated-measures statistics with effect sizes and confidence intervals, and apply appropriate correction strategies for multiple comparisons to improve interpretability and reproducibility. Such work would help distinguish statistically detectable menstrual cycle effects from those that are meaningfully relevant in clinical, academic, or athletic contexts (3,4,15).

CONCLUSION

This study showed that cognitive and neuromuscular performance varied across the menstrual cycle in healthy young women, with the ovulatory phase demonstrating the most favorable overall profile in relation to reaction time, working memory, quadriceps strength, and muscular endurance. These phase-related differences were accompanied by the expected cyclic changes in estrogen and progesterone and were supported by moderate hormone-performance correlations, suggesting that endogenous ovarian hormones may contribute to integrated variation in brain and muscle function. While the observed differences were not large enough to imply impairment outside ovulation, they support recognition of the menstrual cycle as a meaningful biological variable in female performance research and highlight the value of individualized, hormone-informed approaches to assessment, training, and health optimization.

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