The Menstrual Cycle Does Not Influence Joint Position Sense, Joint Kinesthesia, and Dynamic Balance

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THE MENSTRUAL CYCLE DOES NOT INFLUENCE JOINT POSITION SENSE, JOINT KINESTHESIA, OR DYNAMIC BALANCE

By

Kysha Harriell

A DISSEPTION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

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A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

THE MENSTRUAL CYCLE DOES NOT INFLUENCE JOINT POSITION SENSE,
JOINT KINESTHESIA, OR DYNAMIC BALANCE

Kysha Harriell

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Objective: The prevalence of anterior cruciate ligament (ACL) injuries in female athletes appears to be highest during the late luteal and early follicular phases of the menstrual cycle. There may also be a relationship between decrements in proprioception and the prevalence of ACL injuries. The primary purpose of this study was to assess joint kinesthesia, joint position sense, and dynamic balance between the phases of the menstrual cycle.

Design: This study was a longitudinal design. Participants made nine visits to the research facility over a two month period. During these visits, balance, joint kinesthesia, and knee joint position sense were assessed over two consecutive menstrual cycles during the early follicular (Days 2-4), ovulatory (24-48 hours after LH surge detection), and mid-luteal (7 days after ovulation) phases.

Subjects: Nine moderate to highly active females (Age: 23.3 ± 5.0 years, Mass 63.1 ± 11kg, height: 164.2 ± 4.8cm).

Measurements: Joint position sense was tested using starting angles of 90° when moving into extension and 0° when moving into flexion. Target angles were 30°, 50°, and
70° moving into flexion, and 20°, 40°, and 60° moving into extension. Joint kinesthesia was tested moving into flexion and extension at both 15° and 45°.

**Results:** No significant differences were found between the menstrual cycle phases and the threshold to detect motion, joint reposition sense error, or dynamic motion analysis.

**Conclusion:** The menstrual cycle does not affect joint kinesthesia, joint position sense, or dynamic balance in moderate to highly active females.
ACKNOWLEDGEMENTS

Thank you to the Department of Exercise and Sport Sciences for supporting me through the various phases of my educational and professional career.

Thank you to Scott McGonagle for giving me a chance and for being flexible in always allowing me to pursue my goals and dreams.

Thank you to my parents Fred and Patricia for teaching me the value of hard work and perseverance. I miss you Big Fred!!
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CHAPTER ONE: INTRODUCTION

Female athletes are four to eight times more likely to suffer an anterior cruciate ligament (ACL) injury than their male counterparts.\textsuperscript{1,2} Currently, it is widely accepted that the reason for the higher incidence in ACL injuries in females is multifactorial including structural\textsuperscript{43-4}, kinematic,\textsuperscript{15,6} hormonal,\textsuperscript{7,8} and neuromuscular factors.\textsuperscript{7,9-10} Additionally, an association between an increased risk of athletic injuries in females and different phases of the menstrual cycles has been reported.\textsuperscript{1,11-13} Originally, estrogen receptors within the ACL were thought to cause an increase in laxity during different phases of the menstrual cycle, making the ACL more prone to injury;\textsuperscript{3,8} however, more recent studies have not supported this hypothesis,\textsuperscript{14-15} leaving the mechanism for the increased risk of ACL injuries during different phases of the menstrual cycle in question.

There is a growing interest in the role of proprioception as a factor for ACL injuries in female athletes, with reports of proprioceptive decrements during different phases of the menstrual cycle.\textsuperscript{16,17} In addition, there is evidence which shows a direct relationship between decrements in proprioception and ACL injury in males and females.\textsuperscript{10} Studies have also reported that female athletes who participate in proprioceptive training regimens have a decreased incidence of ACL injuries.\textsuperscript{18,19} To date, two studies have demonstrated that the menstrual cycle affects the different sub-modalities of proprioception, joint position sense (JPS) and joint kinesthesia (JK).\textsuperscript{16,17} However, these studies only included females with minimum to moderate activity levels and each study measured only one sub-modality of proprioception. The purpose of this study was to investigate the influence of menstrual cycle phases on joint kinesthesia, joint position sense, and dynamic balance in women with moderate to high activity levels.
CHAPTER 2: METHODS

Subjects

Subjects were recruited from the University of Miami campus area using posted flyers. All potential participants completed a health status questionnaire and were included in the study if they had no history of major knee injury, menstrual irregularity, endocrine disorders, lower limb, vestibular, or neuromuscular disorders, or any other chronic medical condition that could affect performance. In addition, participants may not have taken contraceptive medications over the past six months. The University of Miami’s Institutional Review Board approved the study. The procedures and risks were thoroughly explained to the participants, and their written consent was obtained. A power analysis conducted a priori using an average effect size from previous studies\textsuperscript{16, 17}, indicated a required sample size of at least seven for an effect size of 0.25 and with $p \leq 0.05$. During the initial recruitment period, fourteen moderate to highly active women volunteered for this study. All subjects engaged in moderate to high intensity activity at least 3 times a week. Subjects included a collegiate soccer player, a martial artist, a collegiate track athlete, two recreational dancers, and 4 recreational long distance runners. Five subjects were excluded from the study (three failed to detect ovulation, one had to begin oral contraceptives for a medical condition, and one was found to have a knee injury). Physical characteristics of the nine women who completed the study are presented in Table 1.
Experimental Design

After one day of familiarization with the testing protocol, the subjects were tested a total of six times; three times over two consecutive menstrual cycles. The time points of these tests constituted the independent variables of the study. They were the early follicular, ovulatory and mid-luteal phases of the menstrual cycle. The dependent variables measured were joint position sense error (JPS), joint kinesthesia defined as the threshold to detect passive movement (JK), and the dynamic motion analysis (DMA) scores produced by the Proprio 5000 dynamic stability test.

Tests Familiarization

During the familiarization period, subjects practiced the testing protocol and received instructions concerning when and how to use the Clear Blue Easy (Unipath Diagnostics Co., Princeton, NJ) digital ovulation detector kit. The starting menstrual phase of testing, the order and direction of the target angles for JPS, and the start time and direction of the limb movement for JK were randomized at this time.

Testing Protocol

As reported in previous studies\textsuperscript{20,21}, our JK measurement technique involved subjects sitting in a chair with visual, audio, and tactile cues reduced and the leg supported by an external movement device. The knee was placed at a predetermined starting position and slowly flexed or extended at a random starting time while the subject was instructed to signal when movement was felt. The outcome measure was the number of degrees of movement that the knee moved before the patient detected motion, often referred to as
the *threshold to detect motion*. Specifically, our joint kinesthesia (JK) testing was conducted using the passive setting of the Biodex System 4 dynamometer (Biodex Inc., Shirley, New York). In order to decrease cutaneous cues, the participant sat in the Biodex apparatus with the chair reclined to 20° from vertical and positioned such that the popliteal fossa did not touch the seat bottom when the leg was rested at 90° (See Figure 1). In order to further limit cutaneous cues of movement, the subject’s leg was placed in an inflatable air splint. To limit audio and visual cues to movement, the subject was blindfolded and wore sound muffling (white noise) headphones. Instructions were given to the subject prior to applying the headphones and starting the test. The JK testing procedure included: positioning the subject’s knee at a starting angle of 15° and 45° degrees; instructing the subject that her leg would begin to move at a random time intervals up to 45s after the examiner signaled the start of the test; and finally, passively moving the subject’s knee via the Biodex while having the subject press the stop button once motion was detected. The degrees of movement from the starting angle were recorded using the Biodex’s electronic goniometer. Each subject completed a total of twelve repetitions; three repetitions at each angle (15° and 45°) during both flexion and extension of the knee.

Similar to other studies\textsuperscript{22,23}, our joint position sense technique for the knee involved the reduction of visual clues while moving the knee to a specific target angle, holding that target angle, returning the knee to the starting position, and then reproducing that target angle. The outcome measure is the difference between the target angle and the reproduced angle (in degrees), often referred to as *reposition error*. This technique was
also measured using the Biodex System 4 dynamometer (Biodex Inc., Shirley, New York). The subject sat in the chair of the dynamometer with her knee joint aligned with the shaft of the powerhead with the chair reclined 20 degrees from upright (See Figure 2). The subject’s knee was positioned at a specified starting angle (90° and 0°); passively moved by the Biodex to a specified target angle (30°, 50°, 70° when moving into flexion, 20°, 40°, 60° when moving into extension); held at the target angle position for ten seconds; and passively returned the starting position. The subject’s knee was then passively moved and she was instructed to hit the stop button when she sensed the target angle. The absolute difference between the target angle and the reproduced angle (in degrees) was measured by the Biodex goniometer. The Biodex was calibrated before each testing session to ensure the validity of the measurements.

Dynamic balance was tested on the Proprio 5000 (Perry Dynamics Inc., Decatur, IL), a moveable balance platform designed to objectively measure dynamic balance performance. During the test, the platform randomly moves in different directions, which simulates unexpected body and limb movements as seen in many sporting activities. The Proprio 5000 uses an ultrasonic receiver that is belted to the center of the subject’s low back and a large transmitter located on the back pad of the machine (Figure 3). These ultrasonic waves record motion in a three-dimensional space (anterior to posterior, side to side, and up and down). The Proprio 5000 provides an objective comprehensive dynamic motion analysis (DMA) score. During the test, multidirectional movements are randomly produced and the X, Y, and Z coordinates of the Proprio 5000’s transmitter are recorded every 0.25 second. The total score is calculated by adding up the vector movements from
one point to the next (Perry Dynamics, Inc.). The DMA score is reported as the number of inches the center of gravity (transmitter) moves during the test.

During the DMA test, the ultrasonic sensor belt of the device was placed on the subject’s waist with the transmitter positioned between the spinous processes of lumbar vertebra five (L5) and sacral vertebra one (S1) (See Figure 3). The subject stood on the moveable platform with feet shoulder width apart (See Figure 4). The device incrementally increased the platform angle through random patterns (lateral, up and down, anterior and posterior, clockwise, and counter clockwise). Additionally, the speed gradually increased from 12.65 deg/s to 126.4 deg/s. The test lasted for a maximum of 120s; however, it automatically stopped if the device detected a movement of 7.6 cm (in any direction) in 0.25s or a 12.7 cm displacement in a single direction from the initial starting point.

The data from the ultrasonic sensor of the Proprio 5000 has been found to be highly correlated to sacral marker movement in all three directions. A strong correlation has also been reported between the movement of center of mass (COM) in the lateral and superior/inferior directions and the movement of the Proprio 5000 ultrasonic sensor.

**Statistics**

A 3 (menstrual stage) x 2 (trial) x 2 (angle) x 2 (direction) repeated ANOVA was used to analyze differences in means for the JK data. Separate 3 (menstrual stage) x 2 (trial) x 3 (angle) repeated measures ANOVAs using the absolute means were used to detect differences in JPS in each testing direction.
The Proprio 5000 presents both linear and rotational data resulting from the angle and speed perturbations provided by the device. The translational movements, which included lateral, anterior/posterior, and superior/inferior movements, measured in inches, were combined in a single analysis; while the rotational movements of flexion, lateral flexion and rotation, measured in degrees, were analyzed in a separate analysis. Therefore, two separate 3 (menstrual cycle) x 2 (trial) x 3 (direction) repeated measures ANOVAs were used to analyze DMA directional scores. In addition, a 3 (menstrual cycle) x 2 (trial) repeated measures ANOVA was used to analyze the cumulative DMA score. The PASW Statistics (formally SPSS) for Windows, Version 18, Statistical Program (SPSS, Inc., Chicago, IL) was used for data analysis. When significant stage differences or stage x trial interactions were detected, a Bonferonni post hoc analysis was used to ascertain the source of the differences. Statistical significance was set \( a \ priori \) at \( p \leq 0.05 \).
CHAPTER 3: RESULTS

Joint Kinesthesia

Analysis of the threshold to detect motion revealed no significant main effects or interactions for menstrual cycle phase, trial, angle, or direction (p values ranging from 0.14 to 0.78).

Joint Position Sense

Joint position sense toward the direction of flexion revealed no significant main effects or interactions for menstrual cycle phase, trial, or angle (p values ranging from 0.11 to 0.72). Analysis of JPS toward the direction of extension revealed no main effect for trial or menstrual cycle phase and no interactions for trial, angle, or menstrual cycle phase (p values ranging from 0.08 to 0.93); however, there was a significant main effect for angle (p = 0.03). A post hoc analysis revealed a significant difference between the 40° angle (5.80 ± 1.86) and the 20° (4.54 ± 1.55) and 60° (7.53 ± 3.00) angles. A separate ANOVA conducted for the JPS at the 40° angle showed a significant difference between trials (p = 0.01). Post hoc analysis showed joint reposition sense error was higher during the first trial compared to the second trial (see Figure 5).

Dynamic Motion Analysis Scores

Analysis of DMA scores for translational movements revealed no significant main effects or interactions for menstrual cycle phase, trial, or movement direction (p values ranging from 0.12 to 0.67). Analysis of DMA scores for rotational movements revealed no significant main effects or interactions for menstrual cycle phase, or trial (p values
ranging from 0.23 to 0.85); however, there was a significant difference due to movement
direction (p = 0.006). Post hoc analysis showed significant differences between the
flexion, lateral flexion, and rotational movements (see Figure 6). When analyzing the
cumulative DMA score produced by the Proprio5000, there were no significant main
effects for menstrual cycle phase (p = 0.429) or interactions for menstrual phase and trial
(p = 0.23); however, there was a significant main effect for trial for the cumulative DMA
score (p = 0.009), with the second trial producing better scores than the first.
CHAPTER FOUR: DISCUSSION

The purpose of this study was to examine the influence of the menstrual cycle on joint kinesthesia, joint position sense, and dynamic balance. The primary findings were that the menstrual cycle does not influence joint kinesthesia, joint position sense, or dynamic balance in moderate to highly active females. Our findings are discussed in greater detail below.

Joint Kinesthesia

The mean values for the threshold to detect motion for the joint kinesthesia tests in the current study were similar to those of other studies\textsuperscript{23, 25} (See Table 2). Our results, showing no significant differences in the thresholds to detect motion throughout the menstrual cycle, are similar to those reported by Friden et al\textsuperscript{26} who also reported no variations in the detection of passive movements across menstrual cycle phases, even though women who presented with premenstrual syndrome (PMS) had a greater detection threshold. In contrast, a later study by the same group\textsuperscript{17} reported a decreased ability to detect motion during the premenstrual (our mid-luteal) phase compared to the menstrual and ovulatory phases. However, the differences between these phases were small (0.2 degrees) and their clinical significance was questioned by the authors. The differences in results may be due to differences in instrumentation, and the speed and angles used to measure joint kinesthesia. Friden et al.\textsuperscript{26} used a custom-made device and measured the threshold to detect motion at 20° with a speed of 0.10 deg/sec, while our procedure used the passive setting of the Biodex System 4 dynamometer (Biodex Inc., Shirley, New York) at 15° and 45° with a speed of 0.50 deg/sec.
Joint Position Sense

Our current findings (See Table 3), which detected no significant differences in joint reposition error among the menstrual cycle phases, are similar to the results reported by Hertel et al.27, who reported no significant differences in joint position sense across phases of the menstrual cycle in fourteen female collegiate athletes. However, our findings are in contrast to those presented by Aydog et al.16 who found joint reposition errors to be significantly higher at measured angles of 50° and 70° from flexion during the menstrual and early luteal phases compared to the follicular phase (p < 0.05) and at a target angle of 40° from extension during the menstrual phase compared to the early luteal and follicular phases (p < 0.05). The divergent results between the two studies may be explained, in part, by the differences in menstrual cycle phases tested. Although the JPS testing techniques were identical for both studies, only our menstrual phase testing (Day 2-4 of the menstrual cycle) corresponded to the time points used during their testing protocol. The other two chosen menstrual cycle testing phases represented different physiological and hormonal events within the menstrual cycle. Their finding of significant differences between the menstrual, early luteal, and follicular phases at 50° and 70° in flexion occurred when comparing the menstrual phase to the follicular phase (day 9-11), which is typically denoted by stable hormone concentrations in which estrogen levels are high and progesterone levels are low (see Table 4). Our study did not test subjects during this time period. In addition, their luteal phase (days 16-18 of the menstrual cycle) is typically denoted by high levels of both estrogen and progesterone, whereas our luteal phase testing day (approx. day 21) is defined as a time point when
both estrogen and progesterone begin to decrease in preparation for the follicular phase. Finally, we evaluated subjects during the ovulatory phase of the menstrual cycle while Aydogat al\textsuperscript{24} did not.

Dynamic Balance

The current study is the first to our knowledge to examine the effects of the menstrual cycle on dynamic balance using the Proprio5000 balance platform. In addition, this was also the first study to our knowledge to examine balance across the menstrual cycle in moderate to highly active females.

The tests detected no significant differences in dynamic balance measures among the menstrual cycles. In comparable studies results have been equivocal with researchers reporting lateral sway deficits during the late luteal and early follicular phases of the menstrual cycle\textsuperscript{28}, while others reported no differences in balance among menstrual phases\textsuperscript{26,27}. Our results are similar to those of Friden et al.\textsuperscript{26} who found no significant difference in lateral sway among menstrual cycle phases. Their results did, however, show that women with premenstrual syndrome (PMS) had a significantly greater postural sway and a greater threshold to detect passive movement in the knee than women without PMS. Based on supplemental data collected, none of the subjects in this study reported significant clinical symptoms of PMS.

The significant differences in DMA scores among all rotational movement among flexion, lateral flexion, and rotation, may be due to the different neuromuscular strategies
used to counteract lateral perturbations (ankle dominate) compared to flexion and rotational perturbations (thigh dominate)\textsuperscript{29,30}.

\textit{Limitations}

A limitation of this study was not quantifying hormones to confirm menstrual cycle stages. However, the definitions of the stages of testing were objective and distinct, as the menstrual phase was determined by the presence of menses, the ovulatory phase was defined as 24-48 hours after detection of the LH surge by use of an ovulation detector, and the mid-luteal phase was defined as seven days after LH surge detection. In addition, participants were examined over two menstrual phases to ensure the reliability of the test and the presence of regular menstrual cycle lengths (28-35 days). It should be recognized that studies which measured hormones to confirm menstrual cycle stages still produced equivocal results\textsuperscript{26,27} and no correlation has been found between hormones and changes in balance or joint kinesthesia\textsuperscript{17,26}.

An additional consideration is the significant improvement in the cumulative DMA scores that was seen between trial 1 and trial 2 of the testing, suggesting a learning effect. The cumulative DMA score is computed by adding the number of cm moved during each 0.25 s sampling period in all there testing directions for the duration of the Proprio test. Additionally, a displacement of the transmitter more than 7.62 cm within a single sampling period caused the test to automatically terminate. If a subject does not complete the entire 120 s testing protocol the computer adds a "dummy" value to the total DMA score. For example, if a subject completed 118 seconds of the test, the program
calculated that she had 2 seconds of testing left and added 24 points to her DMA score. The 24 point score is calculated by adding the maximum score of 3 for each of the eight remaining 0.25 s sampling period to the cumulative DMA. This may have dramatically inflated the DMA score when a subject did not finish, and decreased her score if she completed the entire test. For this reason it may be best to consider the directional movement scores, and not the cumulative DMS score, produced by the Proprio 5000 when the device is used as a tool for research.

**Conclusion**

A number of studies have reported decrements in JK, JPS, or balance during the menstrual and the pre-menstrual phases of the menstrual cycle. However, our study as well as others challenge those results. The divergence in results may be due to differences in methodology, including differences in selected menstrual cycle phases and differences in JK, JPS, and balance techniques. Future studies should examine JK, JPS, and dynamic balance across all possible physiological and hormonal events of the menstrual cycle.
REFERENCES


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Figure 4. Subject performing the Proprio 5000 test
Figure 5. Differences in joint position sense due to trial. *significantly lower than Trial 1
Figure 6. Significant differences in DMA scores due to movement direction. *significantly greater than lateral flexion and rotation, †significantly greater than lateral flexion
**TABLES**

*Table 1.* Physical Characteristics of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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<tr>
<td>Age (yr)</td>
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<td>Height (cm)</td>
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<td>Mass (kg)</td>
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<td>Body mass index</td>
<td>23.2 ± 3.2</td>
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Values are means ± SD; n = 9.
Table 2. Joint Kinesthesia Protocol and Results

<table>
<thead>
<tr>
<th>Direction</th>
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<th>Menstrual Phase</th>
<th>Ovulatory Phase</th>
<th>Mid-Luteal Phase</th>
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<tr>
<td>Flexion</td>
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<td>45</td>
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<tr>
<td>Extension</td>
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<td>45</td>
<td>3.50 ± 4.50</td>
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Values are means ± SD; n = 9
Table 3. Joint Position Sense Protocol and Results

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<th>Direction</th>
<th>Starting Angle (degrees)</th>
<th>Target Angle (degrees)</th>
<th>Menstrual Phase</th>
<th>Ovulatory Phase</th>
<th>Mid-Luteal Phase</th>
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<td>Extension</td>
<td>20</td>
<td>4.07 ± 1.31</td>
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<td></td>
<td>40</td>
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<td>60</td>
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<td></td>
<td>70</td>
<td>5.97 ± 4.74</td>
<td>4.74 ± 3.15</td>
<td>5.59 ± 3.99</td>
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Values are means ± SD; n = 9
Table 4. Menstrual Cycle Terminology with Corresponding Days of the Menstrual Cycle and Corresponding Hormone Concentrations of Estrogen and Progesterone

<table>
<thead>
<tr>
<th>Menstrual Cycle Phase</th>
<th>Day</th>
<th>Estrogen</th>
<th>Progesterone</th>
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<tbody>
<tr>
<td>Follicular</td>
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<td></td>
<td></td>
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<tr>
<td>*Early Follicular</td>
<td>2-7</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Mid-Follicular</td>
<td>6-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Follicular</td>
<td>9-13</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>*Mid-Cycle/Ovulatory</td>
<td>12-18</td>
<td>Surge</td>
<td>Surge</td>
</tr>
<tr>
<td>Ovulatory (3-5 days around ovulation)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>*Ovulation</td>
<td>14</td>
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<tr>
<td>Luteal or Postovulatory</td>
<td>15-28</td>
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<tr>
<td>*Mid-luteal</td>
<td>18-24</td>
<td>High</td>
<td>High</td>
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<td>21-28</td>
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<tr>
<td>Late Luteal</td>
<td>24-28</td>
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</tbody>
</table>

Note. Based on a 28-day cycle with ovulation occurring on day 14. *Denotes phases in which subjects were tested. Modified from “Effects of the menstrual cycle on exercise performance,” by X. A. Janse de Jonge, 2003, Sports Medicine, 33 (11), p. 836.