ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202512_8(12).0029

A Review of Differences in Athletic Performance and Training Adaptability Across the Female Menstrual Cycle

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Abstract

The unique female menstrual cycle, accompanied by cyclical fluctuations in sex hormones such as estrogen and progesterone, exerts complex effects on athletic performance and training adaptations. This article systematically reviews relevant literature to summarize differences in athletic performance (e.g., strength, endurance, power) and training adaptability (e.g., muscle hypertrophy, metabolic regulation) across different phases of the menstrual cycle (follicular phase, luteal phase). It analyzes the regulatory mechanisms of hormonal fluctuations, proposes targeted training recommendations, and aims to provide references for optimizing training programs for female athletes and the general fitness population.

Keywords

Menstrual Cycle; Female; Athletic Performance; Training Adaptation; Sex Hormones.

1. Introduction

The female menstrual cycle is a complex physiological process regulated by the neuroendocrine system, typically lasting 21-35 days and divided into four phases: the follicular phase (early, late), ovulation, and the luteal phase (early, mid, late). Sex hormone concentrations (e.g., estrogen, progesterone, luteinizing hormone) exhibit regular fluctuations across these phases, not only regulating reproductive function but also influencing athletic performance and training adaptations by affecting physiological processes such as skeletal muscle metabolism, neuromuscular control, and energy supply [1].

With the increasing participation of women in sports, the impact of the menstrual cycle on exercise has gradually become a research hotspot in sports science. Previous research has predominantly focused on male exercise physiology, while studies on performance differences and training adaptation patterns related to the female menstrual cycle are relatively limited and sometimes yield inconsistent conclusions. Therefore, systematically summarizing existing research findings to clarify the characteristics and mechanisms of athletic performance and training adaptations in each menstrual cycle phase holds significant practical importance for developing personalized training plans, enhancing exercise outcomes, and reducing injury risk.

2. Hormonal Characteristics of Menstrual Cycle Phases

Hormonal fluctuations are the core factor driving physiological changes throughout the menstrual cycle, with distinct hormonal profiles for each phase:

Follicular Phase: In the *early* phase (Days 1-5), both estrogen and progesterone levels are at their lowest, leading to endometrial shedding and menstruation. In the late phase (Days 6-14), estrogen levels gradually rise and peak, progesterone remains low, and luteinizing hormone surges just before ovulation.

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Luteal Phase: After ovulation, the luteal phase begins (Days 15-28). Estrogen levels drop briefly before rising again moderately, while progesterone levels increase significantly, peaking around the mid-luteal phase. Both hormones decline rapidly to baseline levels towards the end of this phase.

These cyclical hormonal changes indirectly influence athletic performance and training adaptations by regulating physiological processes such as skeletal muscle satellite cell activity, protein metabolism, and neurotransmitter release [2].

3. Differences in Athletic Performance Across the Menstrual Cycle

(1) Strength Performance

Most studies suggest that resistance training during the follicular phase leads to more pronounced muscular adaptations, with superior muscle hypertrophy effects compared to the luteal phase. Mechanistically, estrogen can activate skeletal muscle satellite cells, inhibit protein catabolism, and synergize with growth hormone to promote myofibrillar protein synthesis. The significantly higher estrogen levels in the follicular phase provide a favorable physiological basis for strength gains. Some studies also found increased free testosterone levels in the late follicular phase, potentially further enhancing muscle contractile force [3].

However, some meta-analyses indicate no significant differences in strength-related metrics—such as maximal voluntary contraction, isokinetic peak torque, and power—across menstrual cycle phases, with small effect sizes ($g \leq 0.35$). This may be related to heterogeneity in study design (e.g., sample size, training status, testing methods) [4]. Qualitative research finds individual differences in subjectively perceived strength performance, with most women reporting peak strength in the late follicular phase, while strength may decrease and fatigue may increase in the luteal phase due to the catabolic effects of progesterone [5].

(2) Endurance Performance

Differences in endurance performance across the cycle are more evident, with endurance levels generally lower in the luteal phase compared to the follicular phase. Research indicates that elevated progesterone during the luteal phase increases basal body temperature by 0.3-0.5℃, raising thermoregulatory burden and cardiovascular strain, thereby reducing tolerance for prolonged exercise [6]. In hot environments, time to exhaustion is significantly shorter in the luteal phase, whereas endurance performance is more stable in the follicular phase due to lower thermoregulatory stress.

Furthermore, blood lactate clearance rates are lower in the luteal phase compared to the follicular phase, and blood lactate values are significantly higher at the same absolute exercise intensity in the luteal phase, suggesting potential cyclical differences in energy metabolism. However, some studies note that VO_2max, a core indicator of endurance capacity, shows no significant change across menstrual cycle phases, which might be related to individual differences in metabolic regulation and training level [7].

(3) Power and Speed Performance

Differences in power and speed performance across the cycle are less clear-cut. Some studies show better performance in power metrics like squat jump and countermovement jump height during the follicular phase, potentially linked to estrogen's facilitatory effect on neuromuscular excitability. Conversely, studies on soccer players found no significant differences in sprint speed (30m sprint) and countermovement jump height between the follicular and luteal phases [7].

This contradiction may stem from sport-specific demands: short, high-intensity power movements might be less affected by hormonal fluctuations, while power tasks requiring sustained muscle effort might be more susceptible to hormonally influenced muscle metabolic

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status. Additionally, individual differences in hormonal sensitivity could lead to inconsistent performance outcomes.

(4) Performance Related to Injury Risk

The menstrual cycle is closely associated with sports injury risk, particularly concerning anterior cruciate ligament (ACL) injuries. Studies suggest that around ovulation (during the estrogen peak), estrogen may cause joint ligament laxity and decreased neuromuscular control, increasing the risk of non-contact ACL injuries. Moreover, during the early follicular phase, due to low hormone levels, some women experience symptoms like fatigue and lack of concentration, which may indirectly increase the probability of sports injuries [8].

4. Differences in Training Adaptability Across the Menstrual Cycle

(1) Muscle Hypertrophy and Protein Synthesis

A key difference in training adaptation lies in muscle hypertrophy effects. Higher estrogen levels in the follicular phase can enhance the anabolic response to resistance training through mechanisms like activating the AMPK signaling pathway, inhibiting fat synthesis, and promoting satellite cell proliferation and differentiation. Therefore, this phase may be more suitable for high-intensity strength training to maximize muscle hypertrophy [8].

Studies confirm that in resistance training interventions for healthy adult women, the increase in muscle cross-sectional area was significantly greater in groups training primarily in the follicular phase compared to those in the luteal phase. Furthermore, postmenopausal women supplemented with estrogen showed significantly increased myofibrillar protein synthesis rates, further supporting the key role of estrogen in training adaptations [9].

(2) Metabolic Adaptations

The menstrual cycle's regulation of energy metabolism also influences training adaptations. Follicular phase estrogen promotes lipid oxidation, helping to spare glycogen reserves during endurance training and improve energy utilization efficiency. Luteal phase progesterone tends to promote glucose metabolism, potentially leading to faster glycogen depletion and affecting endurance performance during prolonged training [8].

Additionally, estrogen's antioxidant and membrane-stabilizing properties can reduce exercise-induced muscle damage and inflammatory responses, aiding post-exercise recovery and enhancing adaptability to consecutive training sessions. In contrast, the catabolic effects of progesterone in the luteal phase may delay recovery processes and reduce tolerance to training load.

(3) Neuromuscular Adaptations

Cyclical differences in neuromuscular control also affect training adaptations. Follicular phase estrogen can enhance glutamate neurotransmitter release and inhibit GABAergic inhibition, increasing neuromuscular excitability and motor unit recruitment efficiency, which is beneficial for skill learning and motor control. Luteal phase progesterone exerts an inhibitory effect on the nervous system, potentially leading to decreased coordination, prolonged reaction times, and impaired precision of technical movements.

5. Training Recommendations

Based on the characteristics of athletic performance and training adaptability across menstrual cycle phases, the following targeted recommendations are proposed:

Follicular Phase (Focus on Strength Training): The hormonal environment in this phase favors muscle synthesis and strength gains. Consider increasing the frequency and intensity of resistance training, focusing on compound movements (e.g., squats, deadlifts) to promote

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muscle hypertrophy and strength development. High-Intensity Interval Training (HIIT) can also be incorporated to utilize the advantage in lipid oxidation and enhance endurance base.

Luteal Phase (Adjust Training Load and Content): ** Reduce the proportion of high-intensity resistance training to minimize muscle damage risk. Increase aerobic endurance training and technical/tactical skill work. Avoid strenuous exercise in hot environments for prolonged periods. Implement specific training for joint stability (e.g., ACL injury prevention), emphasizing core control and neuromuscular regulation.

Individualized Adjustments: ** Due to individual differences in hormone levels and symptoms (e.g., dysmenorrhea, premenstrual syndrome), it is recommended to identify personal cycle characteristics using menstrual diaries, basal body temperature tracking, or hormone testing. Flexibly adjust training plans based on subjective feelings of fatigue and performance data, avoiding a one-size-fits-all training model.

6. Research Limitations and Future Directions

Current research still has several limitations: Firstly, there are few studies involving elite female athletes; most research involves recreationally active populations, limiting the generalizability of findings. Secondly, studies often focus on resistance and endurance training, with insufficient investigation into cyclical differences in anaerobic endurance and skill-based sports. Thirdly, sample sizes are generally small, and long-term follow-up studies are lacking, making it difficult to determine the long-term effects of cycle-based training.

Future research should focus on: The relationship between the menstrual cycle and performance in elite female athletes; Phase-specific differences in various sports (e.g., team sports, athletics, combat sports); Utilizing hormone testing and molecular biology techniques to deeply analyze the molecular mechanisms by which hormones regulate exercise adaptations; Developing personalized, algorithm-based cycle training guidance for female athletes.

7. Conclusion

The female menstrual cycle significantly influences athletic performance and training adaptations through cyclical fluctuations in sex hormones: The follicular phase offers advantages in muscle strength, hypertrophy, and endurance stability, making it an ideal stage for intensifying strength training. The luteal phase, characterized by increased thermoregulatory pressure and altered metabolism, often shows decreased endurance performance, necessitating adjustments in training load and content.

Understanding these cyclical differences and developing individualized training plans can help optimize training outcomes and reduce injury risk. Future high-quality, large-sample, sport-specific research is needed to provide more scientific theoretical support for training female athletic populations.

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ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202512_8(12).0029

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