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REVIEW ARTICLE

The influence of sex hormones and the menstrual cycle on women's athletic performance: A literature review

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ABSTRACT

The cyclical nature of female sex hormones - primarily estradiol and progesterone - exerts a multidimensional influence on physiological processes relevant to sports performance. This narrative review summarizes the current understanding of how different phases of the menstrual cycle affect energy metabolism, cardiovascular dynamics, neuromuscular function, thermoregulation, and psychological responses in physically active women. Estrogen-dominant phases, especially the late follicular stage, are generally associated with enhanced aerobic capacity, improved vasodilation, mood stabilization, and more efficient motor control. Conversely, progesterone-dominant phases - most notably the mid-to-late luteal stage - are characterized by increased core temperature, fluid retention, fatigue, and greater reliance on carbohydrate metabolism. The review also evaluates the effects of hormonal contraceptives, particularly oral contraceptives, on athletic performance and training adaptations. While individual responses vary, hormonal fluctuations create predictable patterns of performance variability that can be leveraged through phase-aware training. Based on the reviewed literature, the paper suggests practical training strategies, including phase-specific adaptations, nutritional support, and attention to menstrual symptoms. The review further highlights methodological limitations in the literature, including small sample sizes, inconsistent hormone validation, and underrepresentation of elite athletes. A personalized understanding of menstrual physiology enables more effective planning of training loads and recovery strategies, benefiting both professional and recreationally active women.

KEY WORDS: menstrual cycle, estradiol, progesterone, athletic performance, exercise physiology

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INTRODUCTION

SCIENTIFIC CONTEXT AND RATIONALE

The growing participation of women in various forms of physical activity - from recreational exercise to elite-level sport - has highlighted the necessity for an in-depth understanding of sex-specific physiological processes, particularly the impact of cyclical hormonal fluctuations. The female endocrine system is characterized by cyclical fluctuations in estradiol and progesterone, regulated by the hypothalamic–pituitary–ovarian (HPO) axis. These sex hormones exert influence beyond reproductive physiology, affecting cardiovascular, muscular, respiratory, metabolic, and neuroendocrine systems. In contrast to men, women exhibit considerable intra-cycle variability in physiological parameters such as maximal oxygen uptake (VO_2max), lactate threshold, neuromuscular coordination, and recovery dynamics [5].

Despite a growing body of evidence, training protocols often remain standardized and fail to incorporate individual hormonal profiles. This lack of personalization may increase the risk of injuries and endocrine dysfunctions, including relative energy deficiency in sport (RED-S), polycystic ovary syndrome (PCOS), and functional hypothalamic amenorrhea (FHA) [1].

AIM

The objective of this review is to synthesize current knowledge on the influence of estradiol, progesterone, and distinct phases of the menstrual cycle on women's physical performance. Additionally, the review examines the physiological consequences of hormonal contraceptive use in the context of athletic adaptation. Specific areas addressed include:

- Hormonal characteristics and phases of the menstrual cycle;

- Mechanisms of action of sex hormones on major physiological systems;
- Effects of both endogenous and pharmacologically induced hormonal fluctuations on athletic performance variables;
- Practical applications for optimizing training regimens and minimizing injury risk.

MATERIALS AND METHODS

This review summarizes peer-reviewed literature published between 1993 and 2023, focusing on hormonal physiology and exercise science. The selected time frame reflects key methodological advances, including improved endocrine assays, wearable technologies for training load monitoring, and an increased focus on sex-based physiological variability. Earlier studies were excluded due to outdated protocols, methodological limitations, or lack of hormonal phase verification.

Although a scoping review was initially considered, substantial heterogeneity in study aims, populations, and outcomes led to the adoption of a narrative format. This allowed for flexible synthesis across diverse research types, including observational studies, clinical trials, and mechanistic investigations relevant to female athlete care.

Searches were conducted in PubMed, Scopus, and Google Scholar, using Boolean logic and phrase matching with the following string: ("menstrual cycle" OR "estradiol" OR "progesterone" OR "sex hormones") AND ("exercise" OR "athletic performance" OR "training") AND ("women" OR "female athletes"). Filters were applied to include English-language, peer-reviewed studies on human subjects. Backward citation tracking was used to identify additional seminal works.

Search and selection summary:

- ~480 records from PubMed
- ~600 from Scopus
- ~200 manually screened entries from Google Scholar After deduplication and abstract screening (~750 unique records), 160 full texts were reviewed, and 92 studies were included in the final synthesis.

Inclusion criteria:

- Studies on eumenorrheic women (with or without hormonal contraceptive use);
- Assessment of exercise performance metrics (e.g., VO_2max, strength, thermoregulation);
- Preferably included biochemical verification of hormonal phase.

Exclusion criteria:

- Studies involving postmenopausal, adolescent, or pregnant populations;
- Absence of hormonal phase confirmation;
- Irrelevance to exercise physiology or athletic performance.

Both elite and recreational athletes were considered. Final inclusion required methodological transparency, scientific rigor, and relevance to individualized training.

To improve interpretive clarity, studies were classified by evidence level where applicable. Most fell under Level 3–4 (observational or non-randomized designs), with a smaller number classified as Level 2 (e.g., randomized or crossover trials with hormonal confirmation). Meta-analyses and systematic reviews were included where available. Formal risk-of-bias tools were not applied, consistent with the narrative design.

Given the evolving nature of this field, future systematic reviews are warranted. Nonetheless, this synthesis consolidates current high-quality evidence to offer cycle-specific insights and practical guidance for optimizing female athlete performance and health. Due to the heterogeneity of study designs, populations, and outcome measures, formal risk-of-bias assessment tools (e.g., ROBIS or Cochrane criteria) were not applied, as they are not universally compatible with narrative synthesis frameworks.

REVIEW AND DISCUSSION

PHYSIOLOGY OF THE MENSTRUAL CYCLE

HORMONAL PHASES

The menstrual cycle is traditionally divided into three distinct phases, each characterized by specific hormonal profiles and physiological processes:

- **Follicular phase (days 1–14):** This phase is marked by a progressive increase in follicle-stimulating hormone (FSH), which promotes follicular development and stimulates estradiol synthesis. Elevated estradiol levels contribute to improved muscle perfusion, increased glucose uptake via GLUT-4 transporters, enhanced lipid oxidation, and greater metabolic flexibility [9].
- **Ovulation (~day 14):** Ovulation is induced by a mid-cycle surge in luteinizing hormone (LH), leading to the release of the oocyte. At this time, peak estradiol concentrations enhance cardiovascular function and neuromuscular performance. However, elevated estradiol may concurrently reduce the structural integrity of connective tissue, thereby increasing the risk of musculoskeletal injury [14].
- **Luteal phase (days 15–28):** This phase is dominated by progesterone, which elevates core body temperature, promotes fluid retention, reduces insulin sensitivity, and shifts metabolic reliance toward glycogen. These physiological changes may negatively impact endurance capacity and thermoregulatory efficiency [5].

Table 1. Summary of estradiol and progesterone effects on female physiology and athletic performance

Hormone	Primary physiological effects	Performance impact
Estradiol (E2)	↑ Fat oxidation, ↑ glycogen sparing, ↑ mitochondrial efficiency, ↑ nitric oxide (NO) synthesis, ↑ angiogenesis, ↑ muscle protein synthesis	↑ Aerobic capacity, ↑ endurance, ↑ coordination, ↑ recovery, ↑ mood stability
Progesterone (P4)	↑ Core temperature, ↑ fluid retention, ↑ ventilation, ↓ insulin sensitivity, ↑ GABAergic tone, ↓ concentration, ↓ neuromuscular activation	↓ Endurance, ↓ thermoregulation, ↑ fatigue, ↓ cognitive sharpness, ↓ coordination

Sources: adapted from McNulty et al. (2020) [2] Elliott-Sale et al. (2020) [3] Hackney (2016) [5] Constantini et al. (2005) [10] Romero-Moraleda et al. (2019) [11] Martin et al. (2018) [12]

Abbreviations: ↑ increase, ↓ decrease, E2 – estradiol, P4 – progesterone, NO – nitric oxide, GABA – gamma-aminobutyric acid

Table 2. Phase-specific hormonal profiles and their effects on female athletic performance

Cycle Phase	Hormonal Profile	Performance Impact	Risks and Limitations
Early follicular	Low E2, low P4	Supports high-intensity, anaerobic efforts	Menstrual discomfort may reduce motivation
Late follicular	High E2, low P4	Peak aerobic/neuromuscular capacity, fast recovery	Increased ligament laxity; soft tissue vulnerability
Ovulation	E2 peak, LH surge	Maximal focus, reaction time, CNS activation	Higher ACL injury risk in pivot-based sports
Luteal	High P4, moderate E2	Decreased endurance, thermoregulation, mood variability	PMS symptoms, impaired cognition, and fluid retention

Sources: Adapted from Julian et al. (2017) [9] Constantini et al. (2005) [10] Hackney (2016) [5] McNulty et al. (2020) [2] Elliott-Sale et al. (2020) [3] Bruinvels et al. (2017) [20]

HORMONAL INFLUENCE ON PHYSIOLOGY AND FUNCTIONAL IMPLICATIONS

Estradiol and progesterone - key ovarian hormones - modulate a wide range of physiological systems relevant to exercise performance. Among its effects, estradiol has been shown to enhance mitochondrial efficiency and lipid oxidation, while also promoting angiogenesis and better muscle perfusion. It also promotes muscle protein synthesis and neuromuscular coordination, thereby enhancing aerobic capacity, endurance, post-exercise recovery, and psychological resilience.

Conversely, progesterone - dominant in the luteal phase - raises core body temperature, promotes fluid retention and ventilation, reduces insulin sensitivity, and suppresses neuromuscular activation. It may also affect mood, concentration, and thermoregulatory control, particularly under heat stress or psychological load. These opposing hormonal effects contribute to phase-specific performance variability across the menstrual cycle.

Hormonal fluctuations regulated by FSH and LH influence several key systems:

- **Cardiovascular function**: via changes in vascular tone and plasma volume;
- **Muscular adaptation**: through modulation of protein synthesis and satellite cell activity;
- **Neurocognitive performance**: including mood, fatigue, and coordination.

A detailed summary of these hormone-specific physiological mechanisms and their athletic implications is presented in Table 1 (Section 2.3). These concepts are further expanded in subsequent sections, particularly in the context of performance metrics (Section 3) and training strategies (Section 4).

PHYSICAL PERFORMANCE – DEFINITIONS AND COMPONENTS

FUNCTIONAL COMPONENTS OF PHYSICAL PERFORMANCE

Physical performance is a multifactorial trait shaped by the coordinated function of the cardiovascular, muscular, metabolic, and endocrine systems. It enables sustained physical effort across intensities while maintaining energy efficiency, homeostasis, and neuromuscular control.

Key components include:

- **Aerobic capacity**, influenced by VO_2max, cardiac output, and mitochondrial function, tends to improve during the late follicular phase due to estradiol-driven adaptations (Table 1, Section 2.3);
- **Anaerobic capacity**, driven by phosphagen and glycolytic pathways, supports high-intensity bursts but is sensitive to hormonal modulation, particularly under contraceptives with antiandrogenic activity [3];
- **Muscular strength**, shaped by fiber type, cross-sectional area, and protein synthesis pathways, may benefit

from estradiol-facilitated anabolic signaling (Table 1, Section 2.3);

- **Speed and neuromuscular control**, dependent on CNS activation and motor unit recruitment, also vary with hormonal fluctuations - especially around ovulation;
- **Endurance**, integrating metabolic and psychological resilience, is modulated by substrate use and thermoregulatory capacity across the cycle.

Given these hormonal influences, phase-specific training adjustments may enhance adaptation and reduce risk in female athletes.

FEMALE-SPECIFIC BIOLOGICAL FACTORS

Female physical performance is influenced by distinct sex-based anatomical and physiological characteristics. In comparison to males, women generally exhibit lower skeletal muscle mass, a higher percentage of body fat, reduced cardiac chamber dimensions, and decreased hemoglobin concentrations. These factors collectively contribute to a lower VO_2max and diminished absolute power output in female individuals [13, 15, 16].

Furthermore, women tend to possess a higher proportion of type I (oxidative) muscle fibers, which supports superior fatigue resistance and aerobic endurance but may simultaneously constrain maximal strength and power capacity. These sex-specific traits must be considered in the design and interpretation of performance assessments and training interventions.

THE IMPACT OF THE MENSTRUAL CYCLE ON ATHLETIC PERFORMANCE

FOLLICULAR AND OVULATORY PHASES

Consider this: many elite athletes report feeling their strongest mid-cycle. This aligns with estradiol dominance during the follicular and ovulatory phases - periods linked to better aerobic performance and coordination. (see Table 1, Section 2.3). The late follicular phase supports optimal aerobic capacity, neuromuscular efficiency, and recovery, making it suitable for endurance and strength-based training (Table 2, Section 4.3).

In contrast, the early follicular phase - despite low hormone concentrations - may benefit high-intensity and anaerobic efforts, as the absence of progesterone avoids thermogenic and cognitive impairments.

The ovulatory phase, marked by an LH surge and estradiol peak, enhances central nervous system activation, neuromuscular coordination, and psychological readiness. This makes it optimal for speed, power, and skill-based training. However, transient increases in estradiol may elevate ligament laxity and musculoskeletal injury risk, particularly ACL ruptures in multidirectional sports [14].

A summary of performance-relevant hormonal profiles and recommendations is provided in Table 2 (Section 4.3).

LUTEAL PHASE AND PREMENSTRUAL SYNDROME (PMS)

During the luteal phase (days 15–28), the progressive rise in progesterone exerts both thermogenic and catabolic effects. The associated increase in core body temperature may impair thermoregulation, while reductions in lipid oxidation and insulin sensitivity contribute to diminished endurance capacity [10][5]. Additionally, progesterone promotes fluid retention and exacerbates cardiovascular load through activation of the renin–angiotensin–aldosterone system (RAAS). Its modulatory effect on the central nervous system via GABA-A receptors may lead to reduced motivation and impaired cognitive performance [3].

In the late luteal phase, the withdrawal of both estradiol and progesterone can precipitate premenstrual syndrome (PMS), manifesting as mood disturbances, irritability, sleep dysregulation, and reduced adherence to training regimens [16]. PMS may further increase the risk of injury and impede recovery, particularly through its disruption of circadian regulation [17]. Implementing individualized adjustments - such as reducing training intensity or incorporating structured recovery protocols - may support adherence and mitigate physiological stress responses [20].

INDIVIDUAL VARIABILITY AND MONITORING

Physiological and performance-related responses to menstrual cycle phases exhibit considerable interindividual variability. These differences are modulated by factors such as ovulatory function, severity of PMS symptoms, hormonal sensitivity, training status, and genetic predispositions [2][19]. For example, elite endurance athletes with consistent ovulatory cycles may report stable performance across all phases, whereas strength-oriented athletes may experience pronounced impairments in power output, thermoregulatory control, or motivation during the luteal phase.

This variability reveals the limitations of generic training models and emphasizes the need for personalized, hormone-informed planning. Various monitoring strategies - including digital cycle-tracking applications, urinary LH surge detection, and serum hormone assays - enable precise identification of menstrual phases, early detection of cycle disturbances (e.g., anovulation, luteal phase deficiency), and support hormone-informed training periodization.

Improving athletes' awareness of their individual hormonal profiles may enhance self-regulation, psychological resilience, and long-term training consistency. Such approaches contribute to more effective and safer performance optimization throughout the menstrual cycle. Could this explain why two equally trained women respond so differently to the same workout during the luteal phase? Possibly - but more data is needed.

MENSTRUAL CYCLE DISTURBANCES AND ATHLETIC HEALTH

Relative Energy Deficiency in Sport (RED-S) is a clinical syndrome arising from low energy availability (LEA), wherein caloric intake is insufficient to meet the combined demands of exercise and basic physiological functions. This energy imbalance impairs multiple bodily systems, including metabolism, reproductive function, bone health, and cardiovascular regulation. Mechanistically, RED-S disrupts the pulsatile secretion of gonadotropin-releasing hormone (GnRH), leading to suppressed levels of follicle-stimulating hormone (FSH) and luteinizing hormone (LH). This hormonal suppression can result in luteal phase defects, anovulation, or functional hypothalamic amenorrhea (FHA) [1, 8].

Clinical manifestations of RED-S include reduced bone mineral density (BMD), impaired muscle protein synthesis, heightened risk of mood disorders, immune system suppression, and cardiovascular dysregulation.

- **Functional Hypothalamic Amenorrhea (FHA)** represents the most severe form of RED-S-related menstrual dysfunction. FHA is characterized by prolonged hypoestrogenism, resulting in accelerated bone loss, cognitive impairments, and compromised immune function [7]. Therapeutic strategies focus on restoring energy availability through nutritional rehabilitation, psychological support, and modulation of training intensity and volume.
- **Luteal Phase Deficiency (LPD)** is defined by inadequate progesterone production during the luteal phase, impairing post-exercise recovery and extracellular matrix remodeling. Clinical symptoms include chronic fatigue, mood instability, and disrupted thermoregulation [6].

Monitoring implications: The presence of menstrual disturbances should prompt comprehensive endocrine evaluation, including serum levels of estradiol (E2), progesterone (P4), FSH, LH, and thyroid-stimulating hormone (TSH). Additionally, dual-energy X-ray absorptiometry (DEXA) is recommended for assessing bone density, and standardized screening tools should be employed to detect disordered eating behaviors. Early identification and targeted intervention are essential to mitigate long-term health consequences and preserve athletic performance.

HORMONAL CONTRACEPTION AND PHYSICAL PERFORMANCE

TYPES AND MECHANISMS OF ACTION

Hormonal contraceptives modulate female physiology primarily by suppressing the hypothalamic–pituitary–ovarian (HPO) axis, thereby inhibiting ovulation and stabilizing endogenous hormone levels.

- **Combined Hormonal Contraceptives (CHCs):** Contain synthetic estrogen and progestin (e.g., ethinylestradiol and levonorgestrel), delivered via oral tablets, patches, or vaginal rings. They suppress ovulation, stabilize the endometrium, and thicken cervical mucus to prevent fertilization [4].
- **Progestin-Only Contraceptives (POPs):** Include mini-pills, implants, injections (e.g., DMPA), and hormonal IUDs. These primarily thicken cervical mucus and, depending on formulation and dose, may variably suppress ovulation [3].
- **Emergency Contraceptives:** Temporarily inhibit ovulation but are not suitable for long-term use.

PHYSIOLOGICAL AND PERFORMANCE IMPLICATIONS

By flattening natural hormonal fluctuations, hormonal contraceptives can impact performance-related physiology in both beneficial and adverse ways:

- **Positive effects:** Improved menstrual regularity and reduced PMS symptoms may enhance training consistency and psychological readiness.
- **Adverse effects:** Suppressed endogenous estradiol and progesterone can reduce bone mineral density (BMD), impair lean mass development, and affect metabolic flexibility [5].
- **Thermoregulatory changes:** Contraceptive-induced hormonal profiles may mimic luteal-phase conditions, potentially reducing heat tolerance during prolonged exertion in warm environments [5].

Responses vary by progestin type:

- **Androgenic progestins** (e.g., levonorgestrel, norethindrone) may increase insulin resistance and promote unfavorable body composition;
- **Antiandrogenic progestins** (e.g., drospirenone, dienogest) are associated with improved fluid balance and more favorable metabolic outcomes;

Table 3. Performance-related effects of common hormonal contraceptives

Contraceptive type	Mechanism	Hormonal suppression	Performance effects	Drawbacks
CHCs	Suppress FSH/LH; inhibit ovulation	Strong (E2, P4)	Cycle stabilization; reduced PMS	↓ Lean mass, ↑ body temp, altered glucose metabolism
POPs	Mucus thickening; partial ovulation block	Moderate (dose--dependent)	Lower clot risk, flexible use	Variable cycle control; shorter half-life
Hormonal IUD	Local progestin release	Minimal systemic	Fewer systemic side effects	Irregular bleeding; limited performance data
DMPA Injection	Long-acting ovulation suppression	Strong	Long-term cycle suppression	↓ BMD, lean mass loss, possible weight gain
Emergency Contraception	Temporary ovulation suppression	Transient	No long-term impact if used correctly	Hormonal disruption if misused
Contraceptive Type	Mechanism	Hormonal Suppression	Performance Effects	Drawbacks

Sources: Adapted from Elliott-Sale et al. (2020) [3] Ekenros et al. (2022) [4] Hackney (2016) [5] Martin et al. (2018) [12]

• **Depot medroxyprogesterone acetate (DMPA):** Long-acting and often suppresses estrogen markedly, leading to measurable BMD reduction with long-term use, particularly concerning for athletic females.

EVIDENCE OVERVIEW AND PRACTICAL RECOMMENDATIONS

The current body of research presents mixed findings, largely due to methodological heterogeneity across studies. Notable observations include:

• CHCs may contribute to performance stabilization by minimizing hormonal variability throughout the cycle [4];

• CHCs containing antiandrogenic progestins (e.g., drospirenone) have been linked to reduced strength gains and attenuated muscle hypertrophy, likely due to diminished androgen receptor activity in skeletal muscle [12];

• In contrast, CHCs with androgenic progestins (e.g., levonorgestrel) may better preserve anabolic signaling, but can also increase the likelihood of negative mood and metabolic effects;

• Long-term DMPA use is associated with significant decreases in BMD, warranting caution in endurance and strength-trained populations;

• Certain contraceptive formulations may impair insulin sensitivity, with potential consequences for exercise recovery and high-intensity performance capacity [3].

Due to high individual variability in response to hormonal contraceptives, it is recommended that athletes undergo regular monitoring of general well-being, training response patterns, and bone health status. Contraceptive choice should be personalized and aligned with the athlete's sport-specific demands, hormonal tolerance, and overall health objectives.

REVIEW OF SCIENTIFIC EVIDENCE

The influence of the menstrual cycle and hormonal contraceptive use on athletic performance has been explored in cross-sectional, longitudinal, and limited randomized controlled trials (RCTs). Key performance indicators include VO_2max, time to exhaustion, lactate threshold, muscular strength, and perceived exertion.

Multiple studies, including those by Romero-Moraleda et al. [11] and McNulty et al. [17], suggest that the late follicular phase - marked by elevated estradiol - supports improved aerobic capacity and neuromuscular efficiency. However, not all athletes experience these benefits consistently. In fact, Oosthuyse and Bosch [19] reported VO_2max and time-to-exhaustion reductions of 6–8% in some individuals during this same phase. This discrepancy highlights the gap between objective performance metrics and subjective experience. Moreover, premenstrual symptoms may further compromise training adherence and recovery.

However, findings remain inconsistent due to methodological heterogeneity - small sample sizes, varied designs, participant variability, and frequent lack of biochemical phase confirmation. Consequently, most studies are categorized as Level 3–4 evidence (observational or non-randomized), with few robust RCTs or within-subject crossover designs. Underrepresentation of non-Western, adolescent, and perimenopausal cohorts limits broader applicability.

Hormonal contraceptives introduce additional complexity. While some CHCs help stabilize hormonal fluctuations and improve training regularity, others may interfere with anabolic signaling or thermoregulatory responses. In a meta-analysis involving over 40 trials, Elliott-Sale et al. [3] reported an average ~40% reduction in strength adaptation among CHC users compared to eumenorrheic controls, particularly in resistance-based training protocols. Moreover, CHC-related increases in core temperature (~0.3–0.5°C) may further reduce heat tolerance and recovery capacity.

Recent studies show improved methodological rigor [2][4], with growing use of hormonal assays (E2, P4, LH) and multidomain physiological metrics. Meta-analyses [3] support phase-specific trends, though interindividual variability continues to obscure definitive conclusions.

Collectively, these findings highlight the need for precision-based, hormone-informed research to inform individualized strategies in female athlete management.

PRACTICAL IMPLICATIONS FOR FEMALE ATHLETES AND ACTIVE WOMEN

Optimizing performance and preserving health in female athletes requires awareness of cyclical hormonal variability. Menstrual cycle monitoring - via digital apps, basal temperature, HRV, or urinary LH testing - facilitates phase identification and informed training decisions. For clinical accuracy, hormonal assays may be used. Menstrual irregularities such as amenorrhea or luteal insufficiency can signal underlying issues like RED-S or overtraining and should prompt medical evaluation [1].

Training plans should be aligned with hormonal patterns:

- **Late follicular phase** (high estradiol): favorable for high-intensity, strength, and endurance sessions;
- **Luteal phase** (high progesterone): benefits from reduced load, increased recovery, and avoidance of heat stress.

Supportive strategies - such as tailored nutrition (e.g., magnesium, omega-3s), hydration, and PMS symptom management through scheduled deload phases - can improve resilience and consistency [17].

These principles are equally relevant for recreationally active women, especially those over 30 who may face heightened PMS symptoms, irregular cycles, or early perimenopausal changes [18]. Even moderate activity levels may be influenced by phase-specific variations in mood, fatigue, or thermoregulation. Adapting training - for instance, prioritizing restorative work during the late luteal phase and more demanding sessions mid-cycle - can enhance adherence, reduce injury risk, and support well-being.

Key recommendations for coaches and practitioners:

- Normalize open dialogue about menstrual health;
- Use cycle tracking to inform periodized training;
- Refer persistent menstrual dysfunction to healthcare professionals.

Integrating hormonal awareness into training and recovery protocols promotes both peak performance and sustainable athletic development across all activity levels.

CONCLUSIONS

KEY OBSERVATIONS

This review underscores the fundamental role of sex hormones - particularly estradiol and progesterone - in shaping female exercise physiology across multiple systems. As detailed in Table 1 (Section 2.3), estradiol enhances aerobic performance, vascular perfusion, metabolic efficiency, and neuromuscular coordination, while progesterone - predominant during the luteal phase - elevates core temperature, promotes glucose dependence, and may impair both thermoregulation and cognitive performance under physiological stress.

Although cyclical trends in exercise performance are observable, the degree and direction of these changes vary considerably between individuals. Genetic predispositions, hormone receptor sensitivity, training background, and environmental conditions all contribute to this variability, which complicates the formulation of universally applicable training guidelines.

Despite growing interest in this field, current evidence remains limited by small sample sizes, inconsistent performance metrics, and inadequate verification of menstrual phases, underscoring the need for more methodologically robust research [2, 3].

PERSONALIZED AND PHASE-AWARE APPROACHES

Standard training models, often designed with male physiology in mind, rarely account for hormonal cycles. But for women, timing matters. Aligning training with hormone fluctuations may not only improve recovery and performance - it might also reduce injuries. For instance, high-intensity or strength-based sessions may be optimally scheduled during periods of peak estradiol, while regenerative strategies are better suited to the progesterone-dominant luteal phase [17].

Moreover, systematic cycle monitoring enables early identification of dysfunctions such as RED-S, thereby facilitating proactive, individualized interventions. These approaches are consistent with the principles of precision medicine and support a paradigm shift toward athlete-centered coaching frameworks.

LIMITATIONS OF THE REVIEW

As a narrative synthesis, this review provides a comprehensive yet interpretive overview of the existing literature. However, it is subject to several limitations. The selection of studies was based on thematic relevance rather than formal bias assessment, and no meta-analytic techniques were applied. This may limit the generalizability of the findings. Furthermore, the exclusion of grey literature and non-English language publications may have resulted in the omission of relevant data.

RESEARCH AGENDA

To advance the scientific foundation for hormone-informed training in female athletes, future research should prioritize the following:

- Conducting large-scale, controlled studies with biochemical confirmation of menstrual cycle phases;
- Implementing stratification by contraceptive type, sport, and level of athletic performance;
- Integrating psychosocial, nutritional, and chronobiological variables into study designs;
- Investigating the long-term physiological consequences of hormonal manipulation;
- Developing artificial intelligence–driven platforms for real-time, adaptive training personalization.

Pursuing these research directions is essential for translating hormonal science into equitable, evidence-based practices in the context of women's sport and exercise performance.

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DATA AVAILABILITY STATEMENT

Data supporting the findings are available from the corresponding author upon request.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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