The Effect of the Menstrual Cycle on Muscle Performance: A Narrative review

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Abstract

Background: The menstrual cycle (MC) significantly influences womens' physiological functions, affecting endurance, power, and general sports capabilities. Hormonal variations throughout the cycle affect metabolism, recovery process of the muscles, body temperature control, cardiovascular responses, and psychological stability. Understanding these fluctuations is essential for tailoring exercising and competetive plans for women athletes.
Objective: This review consolidates recent research on how different MC phases has an influence on athletic performance, with a particular focus on endurance, power, neuromuscular functionalities, and fatigue perception.
Methods: A comprehensive review of peer-reviewed literature was carried out utilizing databases including PubMed, Scopus, Google scholar and Web of Science.
Results:
Hormonal shifts throughout MC affect endurance, strength, and subjective performance. The follicular stage is associated with improved muscle relief, neuromuscular effectiveness, and cardiovascular function, which may enhance performance; however, Ligament laxity could elevate injury probability. During ovulation, energy attainability is optimized, though heightened joint laxity may increase injury susceptibility. The luteal stage presents physiological difficulties such as a rise in body temperature, cardiovascular tension, and an elevated perception of excertion, which may negatively affect endurance. Despite the fluctuations, there is no universal recommendation for adjusting training based on the MC. Conversly, individualized tracking of menstrual cycle and adaptive training approaches may be more efficient in optimizing sports proficiency in female athletes.

Keywords: menstrual cycle, athletic performance, female athletes, exercise physiology, muscle strength, muscle endurance.

INTRODUCTION

The menstrual cycle (MC) is basically a crucial biological condition in women, primarily preparing the uterus for pregnancy. A typical eumenorrheic cycle lasts about 28 days, though variations are common. Women experience continuous fluctuations in sex hormones, particularly estrogen and progesterone, which impact reproductive functions and multiple body systems, including muscle performance and neuromuscular function [1].

Hormonal changes throughout the MC have an-effect on physical functioning. and the body's reaction to exercise [2]. These fluctuations have significant implications for optimizing exercise programs and understanding the underlying mechanisms of strength-related changes across different points of the cycle. Estrogen and progesterone, the primary ovarian hormones, exhibit distinct effects on neuromuscular function and muscle strength. Estrogen is believed to enhance anabolic activity and neural excitability, while progesterone has suppresive effects on the nervous system [3].

Strength is the capacity to produce force within specific movement limitations. Improving strength is linked to enhanced metabolic health, increased efficiency in daily activities, a reduced likelihood of injuries, and heightened athletic functioning. Furthermore, Strength training provides a significant-role in reducing the impact of conditions linked to muscle weakness, such as sarcopenia, musculoskeletal problems, and extended periods of immobility. It also takes a significant part in reducing risk factors of the injury of anterior-cruciate-ligament (ACL), which are especially prevalent among atheletic females [4].

MATERIALS AND METHODS

Study Design

This review employs a holistic understanding to analyze existing scientific body on the impacts of the MC on sports proficiency. It involves a numerical synthesis of peer-reviewed studies, including meta-analyses and empirical researches. The review specifically examines how different MC phases influence physiological, neuromuscular, and psychological factors related to endurance, power, and general sports proficiency in atheletic females.

Data Sources and Search Strategy

A thorough literature scouring was carried out using online databases such as PubMed, Scopus and Google Scholar. A search strategy was designed to incorporate a combination of relevant keywords and Medical Subject Headings (MeSH) terms, including:

("menstrual cycle" OR "hormonal fluctuations" OR "female hormones") AND ("sports performance" OR "athletic performance" OR "exercise performance") AND ("endurance" OR "aerobic capacity" OR "VO2 max" OR "running efficiency") AND ("strength" OR "muscle power" OR "neuromuscular function") AND ("injury susceptibility" OR "ligament laxity" OR "ACL injury") AND ("psychological aspects" OR "perceived exertion" OR "mood variations") AND (("elite female athletes" OR "trained female athletes") OR ("recreational athletes" AND NOT "sedentary women")).

Ethical Considerations

This study did not feature direct human participation and therefore did not neccissate ethical approval as it’s a narrative review. However, research ethical standards were maintained by double checking that all used studies complied with the guidelines of ethical human research.

Phases of menstrual cycle:

The MC is a physiological activity that takes place in females, preparing the uterus for a potential pregnancy. It involves the periodic shedding of the uterine lining, referred to as menstruation, which results in periodic vaginal bleeding. The length of the cycle usually spans from 21 to 35 days, with 28 days on average, measured from 1st day of one period to the beginning of the following. The onset of cycle of menustration, or menarche, generally occur within the ages of 10 and 16, while menopause, marking the end of menstrual cycles, occurs around an average age of 51 [1].

Two interconnected biological processes constitute the menustraion cycle: the ovarian cycle and the uterine cycle. As for the ovarian cycle, It spans from puberty to menopause and is managed by the hypothalamic-pituitary-ovarian (HPO) axis. Several factors, including the central nervous system, genetic predisposition, and a critical body weight threshold, influence this axis. The anterior pituitary gland releases follicle-stimulating hormone (FSH) and luteinizing hormone (LH) as a result of the hypothalamus' production of gonadotropin-releasing hormone (GnRH). These hormones control ovarian physiological function and drive the menstrual cycle's progression [5].

The MC is made up of three main phases: the follicular phase, ovulation, and the luteal phase. The follicular phase begins on the 1st day of MC and carries on till ovulation, during which estrogen concentration gradually increases while progesterone remains relatively low [6]. This hormonal balance provides several physiological benefits for muscle performance. Estrogen's anti-inflammatory effects aid in minimizing exertion-induced muscle degradation and oxidative stress, promoting enhanced healing and promoting muscular stamina [6]. Moreover, Estrogen promotes neuromuscular function by improving the recruitment of motor unit and the muscle contractility function, which contributes to greater strength and force output. However, it also may increase ligament streching, potentially raising the risk of injury

From a cardiovascular standpoint, estrogen facilitates vasodilation, which enhances oxygen supply to active muscles and improves aerobic functional capacity by optimizing mitochondrial function and promoting enhanced fat oxidation [8] [9]. Additionally, estrogen plays a role in thermal regulation by decreasing body temperature and improving sweating response, enabling athletes to better handle heat stress—an important advantage in endurance sports [6]. Collectively, these physiological effects inferes that the follicular phase may be an suitable period for sports proficiency in female athletes.

Multiple ovarian follicles begin to grow, but only one reaches full maturity while the others undergo regression. Ovulation occurs around the midpoint of the cycle, approximately 10 to 12 hours following the LH surge, leading to the release of an oocyte [10]. During the ovulatory phase, estrogen reaches its peak, accompanied by a sudden increase in luteinizing hormone (LH) [11]. In addition to estrogen's previously mentioned effects, LH contributes a crucial part in setting ovulation in motion and affecting both neuromuscular roles and the regulation of metabolism. At this point in the cycle, progesterone stays decreased, which might promote insulin sensitivity and improve carbohydrate breaking down, potentially allowing greater energy availability for sports proficiency [12][13][14][15][16]. Despite this, hormonal shifts during this phase also affect collagen turnover and ligament tension, resulting in elevated joint laxity and flexibility. This might elevate the risk of injuries, particularly in powerful sports such as football and rugby [17][18].

Following ovulation, the luteal phase commences, during this phase the remainder structure of the dominant follicle changes to corpus luteum. The corpus luteum produces progesterone, which facilitates uterine preparation for possible embryo implantation. This significant increase in progesterone levels bring about notable physiological alterations that can impact sports proficiency. One of the most significant impacts is a core body temperature elevation, which may reduce heat tolerance and negatively affect stamina, especially in hot environments[6]. Furthermore, cardiovascular strain may intensify due to an increase in resting heart rate and cardiac output, possibly resulting in a greater perception of fatigue [19][20].

Strength and Endurance Performance Across the MC:

The connection between MC phases and sports proficiency in endurance and strength-based activities continues to be a key focus in sports scientific researches. Increasing evidence indicates that hormonal alterations affect multiple physiological as well as psychological factors that could influence proficiency. Yet, the degree of these effects varies across subjects and determined by the exercise type performed.

Strength Performance and Neuromuscular Function:

Studies showed discrepencies between men and women in neuromuscular activation, potentially due to hormonal influences [21].The fluctuating levels of sexual hormones, particularly estrogen and progesterone, through out a woman's menstrual cycle, may significantly impact muscle strength and injury risk [22].

Tenan et al. [23] explored the impact of MC on-maximal isometric function of the upper limb muscles and concluded a 23% decrease from ovulation to the mid-luteal phase of the menstrual cycle. **Phillips et al.** [24] found that adductor pollicis muscular strength was 10% higher within the ovulation or luteinization phases in comparison to the follicular phase. Furthermore, **Julian et al.** [25] investigated maximum voluntary handgrip contraction and concluded that grip peak strength was stronger within the secretory phase than during the proliferative and menstrual phases.

ElDeeb et al. [26] found that sedentary women demonstrated higher maximum abductor/adductor torques and peak knee extensor torque within the mid-luteal phase in relation to the early follicular stage, while **Middleton and Wenger** [27] noted enhanced power output during maximal sprints in the luteal phase. **Sarwar et al.** [28] reported an approximate elevation of 11% in the strength of quadriceps at mid-cycle in comparison to the follicular as well as luteal stages, accompanied by greater fatigability. This trend was likely attributed to hormonal fluctuations, especially the estrogen surge prior to ovulation, which has been linked to peak strength in quadriceps and handgrip force.

Pournasiri et al. [29] studied the impacts of various menstrual cycle stages on peak isometric and isokinetic lower-limb strength in athletic females. The research, which involved 37 athletes from sports with a higher injury risk of ACL, assessed knee flexion and extension strength during the follicular, ovulatory, and luteal stages using a Biodex isokinetic dynamometer. The study found that both isometric and isokinetic strength were significantly increased in the ovulatory phase when measured against the follicular as well as luteal phases. These findings infer that muscle strength varies throughout the MC, potentially influencing

ACL injury risk during phases of reduced strength.

Miyazaki et al. [30] examined how hamstring extensibility and muscle power fluctuate across MC in young healthy females, focusing on the follicular, ovulatory, and luteal stages. Results showed that hamstring flexibility (range of motion and passive moment at the pain onset) elevated during the ovulatory and luteal stages, likely due to estrogen's part which it takes in enhancing muscle and connective tissue elasticity. Additionally, passive stiffness was lowest in the ovulatory phase, which may increase joint laxity and injury risk. In contrast, isometrical muscle strength and electromyographic (EMG) activity were markedly increased in the luteal phase when measured against the ovulatory phase, indicating enhanced neuromuscular activation despite reduced flexibility. Interestingly, muscle stiffness and strength did not correlate, suggesting that neuromuscular mechanisms rather than mechanical properties drive strength fluctuations. These findings embark on the importance of adjusting training strategies throughout the cycle, emphasizing injury prevention during the ovulatory phase due to increased laxity and prioritizing strength training during the luteal phase when neuromuscular activation is heightened.

A previous review as well as a meta-analysis by **Niering et al.** [31] on 22 studies indicated that strength performance varies through the MC, with the early follicular phase being the least favorable for maximal strength. The analysis found that peak isometric and dynamic strength occurs in the late follicular stage, conversely, isokinetic strength reaches its highest levels within ovulation.

On the same line, **Pallavi et al.** [32] found an increased increment of 10% in grip peak strength throughout the late follicular stage among active women, with significant discrepancies in handgrip peak strength across the menstrual, late follicular, and late luteal stages. Similarly, **Hudgens et al.** [33] reported improved hand steadiness in late follicular phase in relation to the luteal stage.

Despite the findings, some studies report no marked variations in static handgrip strength through out phases of the menstrual cycle [19][34][35][36][37]. Likewise, **Gorden et al.** [38] observed no discrepancy in muscular strength between the pre- and post-menstrual periods when evaluating handgrip and isometric quadriceps strength in sedentary women.

Gur H. [39] found no differences in quadriceps and hamstring torques among the follicular and luteal phases in sedentary women. Similarly, **Janse de Jonge et al.** [36] observed no discrepancies in quadriceps performance among the menstrual and luteal stages. Other investigations also found no marked changes in college students' isokinetic peak knee extension torque with moderate activity or in peak voluntary isometric contraction in trained women.

Endurance Performance across the MC:

Multiple research demonstrated the impacts of different MC stages on endurance proficiency, including the aerobic capacity, running efficiency, and recovery. A systematic review and also a meta-analysis by **McNulty et al.** [40] suggested that stamina proficiency may be mildly decreased throughout the early follicular phase, when the levels of progesterone and estrogen are the lowest. Similarly, research on stamina - trained women found that this phase was linked to lower quality of sleep and slower recovery after high-level intensity exercising, indicating that hormonal alterations may influence endurance healing processes [41]**.**

Furthermore, studies on elite multisport atheletic females suggest that the effect of the MC on endurance proficiency changes widely among individuals. While some sportsmen report marked declines, others experience little to no alteration, highlighting the need for individualized monitoring [42]. However, despite those subjective accounts, physiological markers such as VO_2 max and duration to fatigue show inconsistent trends across different literatures [40].

Additionally, **Oosthuyse and Bosch** [43] explored how hormonal changes during the MC impact exercise metabolism and performance in eumenorrhoeic women. They observed improved endurance in the mid-luteal phase, as estrogen generally supports endurance by enhancing glucose availability, muscle glycogen storage, and fat oxidation, while progesterone often counteracts these effects by reducing glucose uptake. Performance variations across menstrual phases may be due to shifts in macronutrient metabolism, with the mid-luteal phase (high estrogen) potentially benefiting endurance, whereas the early follicular phase (low estrogen) may be less favorable. However, factors like energy intake, nutrition, and individual hormonal responses contribute to inconsistencies in research findings.

Conversly, an investigation by **Mora Serrano et al.** [44] investigated how menstrual cycle phases influence CrossFit performance in terms of high speed maximal dynamic strength, and muscular endurance. Despite hormonal fluctuations across the cycle, no significant differences were found in jump height, velocity, force, power, or 1-RM strength between the follicular and luteal stages. Similarly, muscular endurance and high-intensity interval exercise performance remained stable across phases, consistent with previous research showing no changes in oxygen consumption, energy expenditure, or relative perceived exertion. However, some athletes subjectively perceived their proficiency to be lower throughg the early follicular and late luteal stages, despite no measurable physiological declines. The investigations suggests that while the menstrual cycle does not objectively impact performance, individual perceptions and symptoms should still be taken into considerations when tailoring training programs for sportswomen. Monitoring the menstrual cycle may help optimize training strategies based on personal comfort and recovery needs rather than physiological limitations.

Fatigue and Performance Variability:

The MC significantly influences fatigue levels and performance variability, particularly in endurance sports and strength-based activities. Hormonal alterations, particularly estrogen and progesterone levels, impacts energy metabolism, neuromuscular coordination, and recovery rates, leading to distinct performance variations throughout the cycle. Several investigations have investigated how different menstrual stages impact fatigue, muscle function, and overall sports proficiency.

Pallavi et al. [45] found that muscle contractions were markedly stronger, more powerful, and less prone to fatigue during the follicular phase when measured against both the luteal and menstrual phases. The highest exertion rates were observed during the menstrual phase, whereas fatigue resistance was more elevated in the follicular phase. These fluctuations throughout the menstrual cycle can impact exercise performance, making it an essential factor to consider in sportive training and selection programs. Therefore, a woman's menstrual cycle plays a critical role in fine tuning training and competition strategies, especially for endurance sports.

Similarly, **Li et al.** [46] studied how physical fatigue fluctuates throughout MC in females with and without generalized anxiety disorder (GAD). Their findings revealed that physical fatigue peaked during the late luteal phase, coinciding with increased progesterone levels, and remained elevated during menstruation. In contrast, fatigue levels were lower within the follicular phase, when estrogen elevates. Women with GAD reported consistently higher fatigue across all phases compared to those without GAD, suggesting that anxiety may exacerbate menstrual cycle-related fatigue. These findings indicate that hormonal fluctuations significantly impact physical fatigue, particularly in women with anxiety disorders.

Furthermore, **Aksu et al.** [47] explored the psychophysiological impacts of the MC in female flag football players, highlighting that perceived fatigue was highest in the luteal phase, where progesterone dominance contributes to increased central fatigue and decreased neuromuscular efficiency. However, the study did not reveal any marked difference between different stages in terms of the study variables, allowing coaches to plan training programs without modifying them according to menstrual cycles. Nevertheless, it is important to consider individual differences and constantly monitor the well-being of athletes.

On the other hand, **Dias** [48] investigated heart rate variability (HRV) thresholds across menstrual phases and found that while cardiovascular performance remained stable, women perceived exercise as harder during the follicular phase. The study suggested that autonomic nervous system responses varied significantly, with greater vagal withdrawal in the follicular phase, possibly leading to higher perceived exertion despite no significant change in endurance capacity or workload.

Lastly, **Julian et al.** [25] examined how different MC phases affect physical proficiency in female soccer players. The researchers assessed a range of performance metrics, including endurance, strength, and sprinting ability, across various cycle phases. Their findings showed a decrease in maximal endurance proficiency throughout the mid-luteal phase of the MC. However, this impact was not noted for jumping and sprint proficiency. Consequently, it might be beneficial to take cycle phase into account when assessing a player's endurance capacity.

Injury Risk and Neuromuscular Function:

Previous literature have measured the parameters of females' physical functional capacity during various MC phases. They found that healthy female athletes with varying hormone levels suggested a potential link between MC phases and ACL injury distribution. In addition, the prevalence of these injuries appears to be affected by fluctuations in estrogen and progesterone levels [49]**.** This association is attributed to the impact of estrogen on ligament collagen, potentially affecting ligamentous laxity [50]**.**

Furthermore, changes in knee joint laxity throughout the MC in response to 17β-estradiol alterations alter neuromuscular control all over the knee joint during running. Women runners use various neuromuscular control tactics during various phases of the MC, which may take part in elevating injury risk of ACL [51]**.**

Moreover, **Johnson et al.** [52] investigated how MC phases influence knee control, muscle activation, and training adaptations during a perturbed single-leg squat (SLS) task in women collegiate athletes. The researchers analyzed performance in the early follicular, late follicular, and mid-luteal phases to determine whether hormonal fluctuations impact neuromuscular control. The study concluded that female collegiate athletes adapt to perturbation training regardless of MC phase, but knee stability and neuromuscular control are greatest during the mid-luteal phase. This phase showed better knee control, higher quadriceps activation, and stronger soleus feedback responses, suggesting enhanced movement stability. These findings imply that ACL injury risk may be lower in the ML phase, highlighting the significance of considering MC phases in training and injury avoidance tactics for women athletes.

On the same line, a systematic review by **Balachandar et al.** [53] examined how the MC affects biomechanics, of lower extremities neuromuscular control, and the risk of ACL injuries in females. The research highlighted that women have significantly higher ACL rupture rates than men in the same sports, prompting investigations into hormonal influences as a potential explanation for this difference. One key finding was that ACL injury risk is highest during the pre-ovulatory phase when estrogen levels peak. During this phase, females tend to experience increased ACL laxity, leading to greater knee valgus and increased tibial lateral rotation during functional movements. These biomechanical changes compromise knee stability, leading to a ligament that is more at risk for excessive strain and injury. This suggests that hormonal fluctuations may directly impact ligament strength, muscle activation, and neuromuscular coordination, raising the injury risks of non-contact ACL tears.

The impact of menstrual cycle on atheletic females' performance:

The influence of the MC on strength-based performance, including maximal strength, power output, and neuromuscular control, remains a topic of ongoing debate. Isenmann et al. [54] evaluated the back squat and jumping performance of female athletes who had received training, and they discovered no significant variations in maximal force output between the various MC phases. Nonetheless, they found that at high performance levels, minor variations in squat performance were associated with the cycle phase, indicating that professional athletes might be more sensitive to hormonal shifts than casual ones.

Similarly, studies on female rugby league players found that the use of hormonal contraceptives or MC had little effect on sprinting efficiency, jump height, or peak force [18]. Researchers have questioned whether cycle-based training modifications are required after a study of professional volleyball players revealed no appreciable variations in power-related effectiveness among MC phases [55].

Conversely, contrasting findings emerged from an examination into isokinetic knee flexor and extensors muscles power in women soccer players. While peak torque remained consistent throughout the cycle, functional strength of the hamstrings was notably decreased through the follicular phase. The researchers suggested that although maximal strength might not be significantly impacted, neuromuscular stability and injury risk indicators could alter, specifically during high-speed eccentric movements. provided the increased susceptibility of female athletes to ACL injuries, these findings highlight the importance of observing neuromuscular control across different stages of the cycle [56].

Likewise, several previous literatur have reported no significant differences in strength or power proficiency among active women. Tests such as handgrip strength and isokinetic knee flexor and extensor assessments have shown consistent results across different MC phases [19] [57] [58].

Effect of Hormonal Contraceptives on Athletic Performance:

Hormonal contraceptives (HCs), which include oral contraceptive pills (OCPs), intrauterine devices (IUDs), and injectables, change natural hormone alterations by preventing ovulation and maintaining consistent estrogen and progesterone levels. These hormonal adjustments can impact metabolism, muscle recovery, and thermal regulation, which may influence athletic performance [59]. Some literature infered that OCP use may reduce muscle protein formation, potentially limiting strength development and recovery in comparison to athletes with a natural menstrual cycle. Furthermore, researches reported that OCPs may affect neuromuscular effectiveness, potentially influencing power output and muscle activation, especially in high intensity or strength based sports [60].

When considering endurance performance, the effects of HCs remain uncertain. Some research suggests that stabilized hormone levels may improve exercise efficiency, while other studies indicate possible reductions in VO_2 max and increased fatigue [40]. Another area of growing interest is the potential influence of HCs on injury risk, with some evidence suggesting that OCP users may have a decreased likelihood of ACL injuries due to decreased ligament laxity and collagen turnover [61]. Regardless of these results, the effect of HCs on sports proficiency varies among individuals, highlighting the need for further investigations to develop tailored training and healing techniques for women athletes.

Moreover, a study found that hormonal contraception (HC) use influences lower-body strength across menstrual cycle phases, whereas naturally menstruating women exhibit consistent strength levels throughout. Specifically, HC users experienced a 5.6% increase in lower-body strength (leg press 1RM) during the high-hormone phase (HHP), while naturally cycling women showed no significant variation between phases. However, upper-body strength (bench press 1RM) remained stable across all menstrual phases and contraceptive conditions, indicating that hormonal fluctuations predominantly affect lower-body muscle groups. Additionally, isometric peak force, vertical jump height, and reactive strength index (RSI) did not change significantly across phases, suggesting that explosive power and neuromuscular performance are less sensitive to hormonal fluctuations. These findings imply that athletes using HC may strategically plan lower-body strength training during their HHP to optimize gains, while naturally menstruating athletes may not need cycle-based training modifications. Overall, the study underscores the individual variability in strength responses to hormonal changes and highlights the need for personalized training approaches for female athletes [62].

In addition, **Brito et al.**[63] scrutinized the impact of hormonal contraception on gut microbiota and metabolic processes. Their results showed that women using hormonal contraception had more stable upper limb strength across the cycle, whereas those with natural cycles exhibited significant variations. Peak strength was observed in the follicular phase, followed by reduced performance in the luteal phase. These findings suggest that hormonal birth control can alter neuromuscular function and metabolism, potentially affecting upper limb endurance and strength at different phases of the MC. Since hormonal contraceptives maintain stable estrogen and progesterone levels, they reduce fluctuations in muscle strength and endurance. In contrast, naturally cycling women experience hormonal peaks and troughs that influence neuromuscular efficiency.

The impact of Menstural cycle on muscle strength differs from atheletic and non-atheletic females?

The MC influences muscle strength differently in athletic and non-athletic women due to differences in hormonal adaptation, neuromuscular control, and training history. Athletes often experience more stable strength levels throughout the cycle due to long-term conditioning, while non-athletes may show greater fluctuations influenced by hormonal shifts. To further explore this distinction, **Kishali et al.** [64] compared performance parameters in athletes and non-athletes across different menstrual cycle phases. The research involved 40 athletes and 40 non-athletes, measuring body weight, fat ratio, resting heart rate, blood pressure, reaction time, hand grip strength, 20m sprint time, and anaerobic power over three months. Athletes demonstrated superior performance in vertical jump, reaction time, hand grip strength, and 20m sprint time, while anaerobic power showed no significant difference. Additionally, no major performance variations were observed between pre-, during-, and post-menstrual phases in both athletes and non-athletes. The study concluded that MC phases did not significantly affect performance in basketball players, volleyball players, judokas, or non-athletes.

Similarly, **Dasa et al.** [65] examined the effects of the MC on strength and power proficiency in high-level women team athletes and found no marked alterations in objective performance metrics across menstrual phases. This finding suggests that long-term training adaptations help maintain neuromuscular function despite hormonal changes. While some athletes subjectively reported higher fatigue levels during the luteal and menstrual phases, their actual force production, muscle activation, and endurance remained stable. In contrast, non-athletes often exhibited greater fluctuations in strength and power output, particularly experiencing reduced performance in the luteal phase. This decrease is likely due to the absence of neuromuscular adaptations that result from regular training. These findings highlight the importance of structured strength training in minimizing the MC's impact on performance, reinforcing the significance of consistent conditioning for female athletes.

On a broader scale, a narrative review done by **Carmichael et al.** [66] analyzed the correlation between the MC and athletic performance. While many studies found no significant performance differences across MC phases, some research suggested that strength and aerobic performance may decline in the late luteal phase, whereas anaerobic performance could be reduced in the late follicular phase. Despite objective measures showing mixed results, many female athletes reported a perceived decline in performance during the late luteal phase. Furthermore, mechanistic factors influencing performance, such as muscle stiffness and metabolism, displayed inconsistent findings, making it challenging to establish clear training guidelines for optimizing training adaptations and athlete management.

In addition, **Soliman et al.** [67] investigated handgrip strength variations in both athletic and non-athletic women across various MC phases to assess how hormonal fluctuations affect muscle function. Their findings revealed that athletic women maintained relatively stable grip strength throughout the cycle, likely due to neuromuscular adaptations from regular training. Conversely, non-athletic participants experienced significant strength declines during the luteal phase, coinciding with peak progesterone levels, which led to increased fatigue and reduced muscle activation. These results recommended that consistent physical training plays a crucial role in mitigating the MC's impact on muscle strength, underscoring the importance of structured exercise in improving female athletic performance.

Training and Injury Prevention Considerations:

Given the influence of menstrual cycle hormones on neuromuscular coordination and muscle contractility, periodized training strategies may be beneficial in optimizing female athletic performance. High-intensity training and skill-based drills are best performed during the follicular phase, when estrogen levels are greater and athletes may experience improved neuromuscular efficiency and muscle contractility. On contrary, because of the higher risk of neuromuscular inhibition and reduced muscle force generation during the luteal phase, which is marked by raised progesterone levels, exercise intensity may need to be adjusted. Incorporating stability exercises, proprioceptive training, and lower-intensity workouts during this phase can help mitigate injury risks.

Building on this, to maximize athletic performance and injury prevention, athletes and coaches should adopt a periodized training approach that aligns with menstrual cycle phases. Strength and power training should be emphasized during the follicular and ovulatory phases, while endurance training and recovery should be prioritized during the luteal and menstrual phases [40]. In support of this approach, **Sung et al.** [68] explored the impacts of follicular-phase-based strength training (FT) versus luteal-phase-based training (LT) on muscle strength, muscle volume, and muscle fiber adaptations in eumenorrheic women. The study found that FT (training primarily in the follicular phase) led to greater strength gains and muscle growth than LT. Specifically, maximum isometric force (Fmax) and muscle diameter (Mdm) increased significantly more with FT. Based on these results, the study recommends that eumenorrheic women should schedule strength training predominantly in the follicular phase for optimal muscle growth and performance improvements.

In addition to structured training phases, monitoring individual cycle responses through tracking apps and self-reported symptoms can help tailor training more effectively [40][51]. Furthermore, implementing neuromuscular control exercises, proper hydration, nutritional strategies, and recovery protocols can significantly enhance performance outcomes while reducing fatigue and injury risk. Since menstrual cycle responses vary among individuals, personalized training adjustments based on each athlete's unique physiological response will yield the best long-term results [40]. A study by **López-Samanes et al.** [69] further emphasized that nutrition and hydration strategies can mitigate some performance declines, especially during high-fatigue phases.

On the psychological side, **Reinertz & Crossland** [70] investigated perceived readiness to train across MC phases in Division II female athletes. They found that athletes reported feeling more psychologically prepared to train through the early luteal phase compared to the follicular phase, though objective performance measures including heart rate variability and jumping performance remained unchanged. The study highlights that psychological factors related to hormonal fluctuations may influence an athlete's training perception, even when physical performance is unaffected. Therefore, training should be adjusted based on individual psychological responses rather than strictly on menstrual cycle phases. Coaches can implement flexible periodization strategies, ensuring that athletes feel mentally prepared and physically optimized for performance.

DISCUSSION

This review sheds light on the specific correlation between the MC and female sport performance, indicating how hormonal fluctuations affect neuromuscular function, endurance, and strength. The follicular phase is linked to greater ligament laxity, which may increase the possibility of injury, even if physiological research indicates that it may have benefits including improved muscle recovery, neuromuscular performance, and thermoregulation. In contrast, the luteal phase provide physiological challenges, including increased core body temperature, increased cardiovascular strain, and a greater perception of exertion, which may negatively impact endurance. However, the degree to which these effects manifest varies significantly between individuals, emphasizing the importance of personalized training and competition strategies.

It is still up for debate how the MC affects endurance performance. While some studies find negligible changes in important performance measures like VO_2 max and time to fatigue, others show a mild drop in aerobic capacity throughout the early follicular phase owing to decreasing estrogen and progesterone levels. Similarly, strength performance appears to be rather constant throughout MC stages, with only minor variations noted in elite sportswomen. Variations in neuromuscular control and functional hamstring power, however, may make people more prone to injuries, especially in sports requiring for rapid movement and eccentric muscle contraction.

These results highlight the need of taking psychological and physiological aspects into account when creating training plans for female athletes. Larger sample sizes, standardized study methods, and individually tailored performance assessments should all be incorporated into future research initiatives in an effort to address the discrepancies in the current literature. Furthermore, even though female athletes frequently use hormonal contraceptives, further research is needed to determine how they affect performance and injury risk. Examining how MC phases, diet, recovery approaches, and training modifications interact may contribute to the development of more thorough recommendations for maximizing women's athletic performance

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