

Systematic Review

Influence of Menstrual Cycle Phases on Muscle Activation in Women: A Systematic Review

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Abstract

This systematic review examined the influence of menstrual cycle phases on lower-limb muscle activation patterns in eumenorrheic women. Following the PRISMA guidelines, a comprehensive search was conducted in PubMed, Web of Science, and SPORTDiscus using the keywords: (menstrual cycle OR menstrual phase* OR menstruation) AND (neuromuscular activation OR muscle activation OR muscle activity OR neuromuscular control patterns) AND (electromyography OR EMG). Inclusion criteria required participants to be eumenorrheic women with regular menstrual cycles, verified through blood analysis and other physiological confirmation methods, and without menstrual disorders or hormonal contraceptive use. Additionally, eligible studies had to assess lower-limb muscle activation using electromyography. Seven studies met the criteria, comprising a total of 116 eumenorrheic women. Most studies reported no statistically significant differences in muscle activation patterns across menstrual cycle phases. Overall, hormonal fluctuations may influence muscle activation depending on the nature of the task performed (dynamic vs. static; fatiguing vs. non-fatiguing). Future research should incorporate larger sample sizes, longer monitoring periods, and more standardized methodological approaches.

Keywords: electromyography; menstrual cycle; muscle activation; neuromuscular control; women



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1. Introduction

In recent years, with the increasing participation of women in society, female athletes have taken on a more prominent role in sport [1,2]. However, most research evaluating neuromuscular performance has been conducted in men, and findings are often generalized to women. This approach overlooks anatomical, biomechanical, psychological, and hormonal differences between sexes [3,4]. Consequently, hormonal fluctuations associated with the menstrual cycle (MC) are frequently disregarded.

The MC is a physiological process occurring during a woman's reproductive years that prepares the uterus for potential pregnancy. Its average duration is approximately 28 days, although this may vary among women due to external factors [5]. The MC is commonly divided into three main phases: (1) the follicular phase (FP), (2) ovulation (OV),

and (3) the luteal phase (LP) [6,7]. The FP is further subdivided into the early follicular phase (EFP; days 1–5, characterized by low estrogen and progesterone levels) and the late follicular phase (LFP; days 6–12, during which estrogen levels exceed progesterone).

During OV (days 13–15), estrogen levels decline slightly relative to the LFP but remain higher than during the EFP. The final phase considered in this review was the mid-luteal phase (MLP; days 20–23), approximately seven days after OV, when progesterone levels exceed estrogen levels, while estrogen remains higher than in the EFP and OV but lower than in the LFP.

These hormonal fluctuations, regulated by the hypothalamic–pituitary–ovarian axis, influence not only reproductive function but also various physiological systems [8–10] including fatigue [11], injury risk [12], coordination, and metabolism [13]. These effects may have important implications for athletic performance and neuromuscular control [4,14,15].

Estrogen has traditionally been associated with the regulation of anabolic processes [13,16] and may modulate central nervous system function [7], enhancing neural transmission by increasing nerve conduction velocity [17] and potentially improving force-generation capacity during phases with high estrogen levels [18]. According to [19], increased estrogen concentrations may reduce collagen synthesis, resulting in mechanical changes in muscles, tendons, and ligaments, which could decrease neuromuscular control and/or joint stability. In contrast, progesterone is traditionally associated with catabolic effects on muscle due to increased amino acid oxidation and protein degradation [20].

Although the maximum voluntary muscle strength depends on cortical excitation transmitted through motor neurons to muscle fibers—and maximum voluntary contraction (MVC) variability is influenced by neural factors such as motor unit recruitment and firing rates [21]—the effects of hormonal fluctuations across the MC on muscle activation patterns remain controversial. Some studies have reported differences between phases [8,22,23], while others found no significant changes in neuromuscular variables [24,25] or activation levels [21,26–29].

Several studies have shown that fatigue-inducing training stimuli and improvements in rapid force production are closely related to individual neural and hormonal profiles [30]. Furthermore, the interaction between estrogen, progesterone, and serotonin appears to enhance force production at the beginning of exercise but impairs it under fatigued conditions [31]. Estrogen concentrations drop just before menstruation, which may compromise neuromuscular control [32]. This decrease may subsequently influence the relative contribution of central and peripheral mechanisms to fatigability.

Evidence from [33] suggests that alterations in neuromuscular control across MC phases may contribute to injury risk during functional tasks. Limited evidence also indicates that estrogen may increase quadriceps contractile strength and prolong relaxation time during OV [34]. One proposed hypothesis is that fluctuations in serum estrogen across the MC may influence muscle function [35]. However, additional high-quality evidence is needed to clarify potential changes in neuromuscular control across phases of the MC.

According to [36], injury incidence is 2- to 8-times higher in women than in men performing similar activities. One important contributing factor may be differences in muscle activation patterns [12,37], which affect joint stabilization through force generation [38]. Neuromuscular function involves integrating neural signals and translating them into force production by the musculotendinous unit, and this function may differ between sexes partly due to hormonal influences. Women tend to exhibit lower hamstring pre-activation and reduced hamstrings-to-quadriceps ratios (H/Q) [37,39], higher quadriceps activation, and lower gluteus maximus activity during landing tasks [40–42]. Moreover, Ref. [43] reported that women may demonstrate superior neuromuscular synchronization—such

as improved right–left leg coordination—particularly in core and lower-limb muscles, whereas men showed greater asymmetries.

The inconsistencies among studies may reflect methodological differences, including methods used to determine and verify MC phases, the inclusion of women with LP deficiencies or anovulatory cycles, differences in phase comparisons, and external factors such as temperature, hydration, or physical activity levels [14]. Therefore, robust methodologies are needed to evaluate muscle activity during different MC phases.

Electromyography (EMG) is an essential tool for assessing neuromuscular coordination and central nervous system function, helping identify muscle imbalances, optimize performance, and reduce injury risk in athletes. Furthermore, given the substantial gap in the literature regarding muscle activation patterns across MC phases, the use of EMG to analyze neuromuscular excitability is especially relevant due to hormonal fluctuations in eumenorrheic women and their potential influence on injury risk during dynamic actions such as jumping, changing direction, or landing.

Existing systematic reviews have primarily examined MC effects on injury risks, biomechanics, or performance outcomes, but none have specifically synthesized how MC phases influence muscle activation patterns assessed via EMG. Because muscle activation represents the mechanistic link between endocrine fluctuations and joint loading, understanding these phase-dependent neuromuscular adaptations is critical. This perspective integrates female endocrinology with bioengineering approaches to motor control and biomechanical modeling. Such evidence is crucial to advance individualized training and injury prevention strategies tailored to women’s physiological variability.

Therefore, to our knowledge, this is the first novel systematic review to critically evaluate electromyographic findings on lower-limb muscle activation across MC phases in eumenorrheic women. Based on the hormonal fluctuations across physiological systems in these women, we hypothesize that MC phases may modulate muscle activation in a task-dependent manner.

2. Materials and Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [44] were followed as the primary methodological reference for this review [45]. The systematic review protocol was registered and accessed at the International Prospective Register of Systematic Reviews (PROSPERO: CRD420261306615). Figure 1 provides an overview of the study selection and screening process. This systematic search aimed to gather and analyze evidence on the influence of MC phases on lower-limb muscle activation, as assessed by EMG, in healthy eumenorrheic women. The research question was formulated following the FINER (Feasible, Interesting, Novel, Ethical, and Relevant) criteria: How do the MC phases influence muscle activation patterns in eumenorrheic women?

2.1. Search Strategies and Sources Consulted

Three electronic databases—PubMed, Web of Science (WOS), and SPORTDiscus—were searched to identify relevant studies. Keywords included: “Menstrual Cycle”, “Luteal Phase”, “Follicular Phase”, “Athletic Performance”, “Neuromuscular Patterns”, “Muscle Activation”, “Maximal Voluntary Contraction”, and “Sports Performance”. These terms were combined using the Boolean operators OR and AND. The comprehensive electronic database searches were conducted between December 2024 and February 2025.

Keywords were allowed to appear in the title, abstract, or author-provided keywords. No publication date limits were applied to ensure a comprehensive and contextually robust search, minimizing the risk of omitting relevant studies, and studies must have involved human female participants and published as original research articles. Reference lists

from previous systematic reviews and related articles were also screened, and unavailable articles were requested directly from the authors via ResearchGate or email.

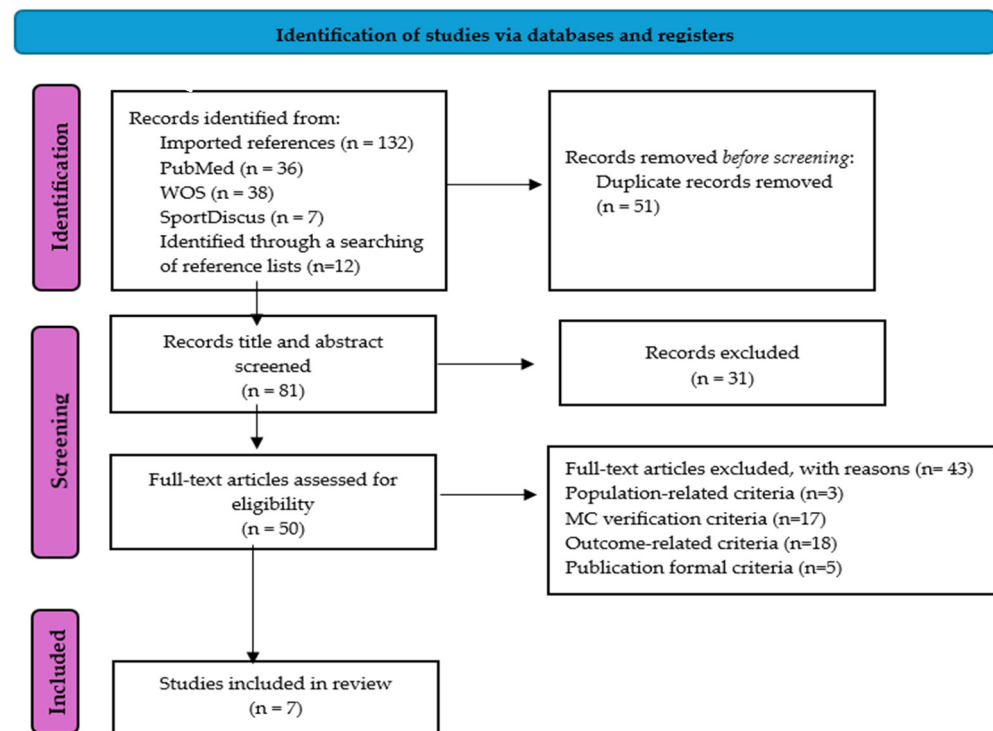


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines flowchart for the literature search and study selection.

The final search expression was:

(menstrual cycle OR menstrual phase* OR menstruation) AND (neuromuscular activation OR muscle activation OR muscle activity OR neuromuscular control patterns) AND (electromyography OR EMG)

The complete database-specific search strings for each database are provided in Supplementary Material File S1: Search strategy and MeSH.

2.2. Inclusion and Exclusion Criteria

The selection of studies for this review was carried out using the PICO (population, intervention, comparator, outcome, study design) framework as a reference to enable a synthesis of the methodology and selection of studies, as shown in Table 1.

The inclusion criteria were studies that included women between 18 and 40 years of age with an MC duration of 21–35 days [46], who were not taking any hormonal contraceptives, were not pregnant, and did not have MC disorders (e.g., menopause or polycystic ovary syndrome).

To assess the influence of the MC phases on muscle activation, the FP (1–13 days) was chosen as the comparator phase with the other phases, which is characterized by variations in hormone concentrations [47]. Likewise, the studies had to verify the phases of the MC with blood samples, and optionally, with other methods such as urinary, saliva samples, and/or basal body temperature, combined with self-reported estimates. If the study did not include the mandatory verification of the MC with blood samples, it was excluded.

In relation to outcomes, variables related to muscle activation patterns were collected, such as RMS (root mean square), %MVC, onset timing (ms), and firing rate (Hz). Studies that did not use EMG to evaluate these variables were excluded.

In terms of study design, all studies in English were included, with no filter applied in terms of year of publication. Observational studies, case studies, and experimental studies were included, provided that they were conducted in humans and had the primary or secondary objective of identifying muscle activation patterns in relation to the phases of the MC.

Table 1. Eligibility criteria.

	Inclusion	Exclusion
Population	Eumenorrheic women; age: 18–40 years; MC length: 21–35 days	Women with any of the following conditions: OC users, MC irregularities (e.g., menopause, polycystic ovary syndrome), injuries, diseases, and smoking behavior
Intervention	Studies conducting interventions on the lower limb with EMG	No EMG method; muscular activity in the upper limb
Comparator	FP was assessed; MC phases must be assessed by blood samples and other procedures: saliva samples, urinary tests, basal body temperature, and self-reported (with a combination of others)	No FP as comparator; only self-reported for the MC assessment; no comparison between MC phases
Outcomes	Articles analyzing muscle activation patterns throughout the MC phases as %MVC or MVC, RMS, onset timing, and firing rate (Hz)	Studies that did not address the outcome question; studies that did not normalize the EMG signal
Study Design	Articles available in English; articles with human beings; descriptive, experimental, or case studies.	Thesis and articles published in other languages; articles with animal intervention; no conference proceedings

MC: menstrual cycle; OC: oral contraceptive; EMG: electromyography; FP: follicular phase; %MVC: % maximum voluntary contraction; RMS: root mean square.

2.3. Quality Assessment of Included Studies

Study selection was first managed using Rayyan (Rayyan Systems, Inc., Cambridge, MA, USA) [48], which facilitated the removal of duplicates and the screening of titles, abstracts, and full texts. Screening criteria included terms such as “menstrual cycle”, “muscle activity”, “electromyography” (inclusion), and “men”, “oral contraceptives”, “injuries” (exclusion).

2.3.1. Physiological Verification Assessment

Study quality was assessed by one reviewer and independently verified by three members of the research team using criteria based on a Downs and Black-based quality assessment with additional criteria in order to assess the physiological verification of MC. As recommended in [49], a modified version of the Downs and Black checklist was used following adaptations described in [7,50], which was specifically tailored for use in this review (see Electronic Supplementary Materials File S2: Quality appraisal for physiological verification—modified Downs and Black checklist).

The original Downs and Black checklist was modified to better reflect the methodological specificities of MC research (from a total of 28 questions to 17 questions, including the 2 additional questions). Items related to traditional clinical trial features—such as intervention description, allocation concealment, group recruitment procedures, and certain aspects of external validity—were removed or adapted, as most included studies used

within-subject or crossover designs rather than parallel-group interventions. The item assessing intervention description was reformulated to require the precise reporting of MC or oral contraceptive phase definitions, acknowledging that accurate phase classification represents a central methodological concern in this field. Additional items were introduced to address factors particularly relevant to exercise and neuromuscular research including the confirmation of habitual contraceptive use or non-use, familiarization procedures, standardization of testing conditions (e.g., time of day, nutrition, prior exercise), randomization or counterbalancing of phase order, and study retention. The original multi-point power scoring system was simplified to reflect whether an a priori power calculation was reported. Importantly, the modified tool incorporated a phase-verification downgrading system (Q1) and (Q2), whereby studies not confirming the MC phase via blood hormone analysis—or, secondarily, ovulation kits—were downgraded in overall quality rating. These adaptations were implemented to prioritize hormonal verification, internal validity, and the control of physiological confounders, thereby enhancing the methodological relevance of the checklist for menstrual cycle research.

The modified checklist includes items on reporting (1–6), external validity (7), internal validity—bias (8–12), confounding (13), and power (14–15). Items are scored as 1 (“yes”) or 0 (“no”/“unable to determine”). Item 9 may score 0, 1, or 2 depending on the degree of standardization of relevant factors. Study quality was classified as: very low (0–5), low (6–9), moderate (10–13), or high (14–16).

After obtaining the raw quality score, two key questions were applied to assess the directness of evidence [51]:

- (Q1) Were MC phases verified using blood samples?
- (Q2) Were urinary ovulation tests used to verify ovulation?

If MC phases were not verified using blood sampling, the study quality was downgraded by one level. A second downgrade was applied if urinary ovulation tests were also absent. Disagreements were resolved through discussion among all authors.

2.3.2. Level of Evidence

Levels of evidence were assigned based on study design. Both observational and experimental studies were included, and most were classified as having moderate methodological quality (Table 2).

2.3.3. Critical Appraisal Assessment. Quality Assurance Process

One investigator independently performed abstract screening, full-text reviews, and information extraction for quality assessment. As with the Downs and Black checklist, if there were disagreements for each component of the AXIS tools, they were resolved through consensus with the rest of the research team.

The quality background was performed in different steps: (a) all records identified through data-base searching were imported into Rayyan (Rayyan Systems, Inc., Cambridge, MA, USA) [49]; (b) after removing duplicates, the titles and abstracts of these articles were screened; (c) the full text articles were assessed for eligibility depending on selection criteria; and (d) the main quality of the included studies was appraised by using the Appraisal Tool for Cross-Sectional Studies (AXIS tool) with 20 components (see Electronic Supplementary Materials File S3: Quality appraisal—AXIS TOOL). Each question in the AXIS tool was answered as “yes”, “no”, “unclear”, or “not applicable”.

Table 2. Methodological quality assessment of the included studies and quality of evidence.

Author	Reporting					External Validity	Internal Validity-Bias						Confounding	Power		A priori	Q1	Q2	Final Grade
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15				
[22]	1	1	1	1	1	1	0	1	0	0	1	1	1	0	0	10	y	n	L
[52]	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	13	y	y	M
[53]	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	13	y	y	M
[54]	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	13	y	y	M
[47]	1	1	1	1	1	1	1	1	2	1	1	1	1	0	0	14	y	y	H
[55]	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	13	y	n	L
[56]	1	1	1	1	1	1	1	1	2	1	1	1	0	0	0	13	y	y	M

H: high quality; M: moderate quality; L: low quality; Q: Question; y: yes; n: no.

3. Results

3.1. Selection of Articles

The search initially identified 132 records. After removing 51 duplicates, 81 articles were screened by title and abstract, and 31 were excluded. Of the 50 full-text articles assessed, 43 were excluded for reasons such as: population-related criteria ($n = 3$), MC verification criteria ($n = 17$), outcome-related criteria ($n = 18$), and publication formal criteria ($n = 5$).

Seven studies met all of the strict inclusion criteria, particularly the gold standard verification of MC phases (blood samples), and were included. Due to heterogeneity across study designs and outcomes, a narrative synthesis was conducted. The PRISMA flowchart summarizes the selection process (Figure 1).

3.2. Study Characteristics

Seven studies were included (Table 3), showing variability in populations, tasks, and EMG outcomes.

3.2.1. Population

A total of 116 eumenorrheic women aged 19–30 years participated. All had regular MCs (21–35 days), no hormonal contraceptive use, no pregnancy or lower-limb injuries, and no conditions affecting sex hormones.

3.2.2. Menstrual Cycle Phases

All studies assessed muscle activation within a single MC. The EFP and/or LFP were examined in all studies ($n = 7$), and four also included the ovulation phase ($n = 4$). Three studies subdivided the FP ($n = 3$), and six assessed the LP—mainly the MLP. One study also included the premenstrual phase [47]. Across the included studies, MC phase verification was performed using quantitative serum hormone concentrations. Ref. [56] determined that the minimal detection concentration of 17β -estradiol was 5 pg/mL (as well as [52]) and progesterone was 4 pg/mL. The sensitivity for serum hormone in [53] was 55 pmol/L for estradiol, 0.95 nmol/mL for progesterone, and 0.05 mIU/L for LH, while Ref. [55] used 75 μ L for the estradiol analysis and 20 μ L for the progesterone analysis. To ensure the physiological validity of the included sample, Table 4 shows the exact quantitative thresholds used by the included studies to confirm the MC phases. Considerable heterogeneity was observed in the operational definitions of MC phases across the included studies. As shown in Table 5, substantial variability existed in the timing and criteria used to define the OV, MLP, and FP subdivisions. Differences were evident in the hormonal thresholds applied, the temporal windows selected, and the methods used to confirm phase occurrence, despite blood-based verification. This variability complicates direct comparisons between studies.

Table 3. Main characteristics of the studies.

Authors and Year	Study Design	Sample Size	Population		Observation Time	Menstrual Cycle		EMG	
			Age Range	Training Status		Menstrual Phases (Days)	MC Verification	Exercise	Variables Analyzed
[47]	Randomized crossover	n = 10	20–25	Handball players	One MC (28–30 days)	LFP: 11–13 MLP: 21–23 PP: 28–29	Blood samples, menstruation diary, and OV test	RSE session (20 × 5'' sprints)	MVC, peak force, EMG signals
[55]	Longitudinal block	n = 15	19–27	Non-athletic collegiate females	One MC (26–31 days)	EFP: 1–3 LFP: 11–13 LP: 21–24	Sublingual morning temperature, blood samples	Single-leg drop landings	Electromyography (gluteus medius onset) and knee kinematics (valgus angle)
[22]	Repeated measures	n = 26	20.5 ± 1.9	-	One MC (26–32 days)	EFP: 1–3 LFP: 11–13 MLP: 21–24	Blood samples	Drop jump	Varus/valgus knee angle and EMG activity
[54]	Descriptive	n = 28	21.0 ± 0.8	Healthy women	One MC (22–24 days)	M: 1–5 FP: 7–10 OV: 12–15 LP: 7–9 after +	Blood samples and Ovulation Urine Test (vaginal smear and ovulation pain)	Single-leg drop landing	Width of the tibiofibular syndesmosis, peak ground-reaction force, time to peak GRF, angles of the hip, knee, and ankle joints, and muscle activity
[53]	Experimental	n = 16	26 ± 4	Healthy women	One MC (28.3 ± 2.3)	EFP: 2–4 LFP: 7–11 OV: 24–28 h after + urinary test MLP: 7 after +	Blood samples and ovulation tests	Dynamic power-type loading protocol	Neuromuscular properties, force production, and metabolic capacities
[52]	Descriptive	n = 12	25.6 ± 3.7	Runners	One MC (28 ± 1.1)	EFP: 1–2 OV: 24–48 h after +	Blood samples and ovulation kits	Treadmill running	Knee joint laxity and EMG activity
[56]	Descriptive	n = 9	24.2 ± 3.2	Recreationally active	One MC (21–35 days)	EFP: within 48 h of onset M OV: within 48 h after + MLP: after 7 following OV	Blood samples and ovulation kits	Force dynamometer	Knee extensor maximum voluntary contraction, jump power, force steadiness, and balance

M: menstruation; PP: premenstrual phase; EFP: early follicular phase; LFP: late follicular phase; FP: follicular phase; OV: ovulation; MLP: midluteal phase; LP: luteal phase; RSE: repeated sprint exercise.

Table 4. Hormone levels by cycle phases of the included studies.

Study	Hormone Levels	MC Phases				
		EFP or M	FP	OV	LP	PP
[22]	Estradiol (pg/mL)	41 ± 24.4	158.5 ± 129.0		135.8 ± 101.9	
	Progesterone (ng/mL)	0.6 ± 0.4				
[47]	Estrogen (pg/mL)		386.91 ± 31.88		194 ± 6.02	77.48 ± 6.49
	Progesterone (ng/mL)		0.54 ± 0.18		14.61 ± 1.68	1.77 ± 0.62
[56]	Estrogen (pg/mL)	244		533	484	
	Progesterone (ng/mL)	2.66		3.22		5.89
[53]	Estradiol (pmol/L)	478.3	592	798.7	684.5	
	Progesterone (nmol/L)	1.9	1	4.1	14.8	
[55]	Estradiol (pg/mL)	28.07 ± 19.40	178.70 ± 164.70		136.10 ± 70.60	
	Progesterone (nmol/L)	0.98 ± 0.46	0.95 ± 0.50		7.78 ± 4.79	
[54]	Estradiol (pg/mL)	24.8 ± 9.8	31.1 ± 13.8	83.1 ± 53.7	94 ± 41.5	
	Progesterone (ng/mL)	0.69 ± 0.20	0.66 ± 0.27	1.92 ± 1.86	10.40 ± 7.02	
[52]	Estradiol (pg/mL)	34.17 ± 15.47		207.74 ± 53.42		

3.2.3. EMG Tasks, Variables Analyzed, and Normalized EMG Amplitudes

Among all the studies analyzed, six used surface EMG ($n = 6$) (Table 5) and one used intramuscular EMG ($n = 1$) [56] (Table 6). In terms of the muscles analyzed, five articles included the quadriceps muscles (“vastus lateralis, vastus medialis and rectus femoris and vastus medialis obliquus”) ($n = 5$), three analyzed the gluteal complex muscles (“gluteus medius and gluteus maximus”) ($n = 3$), four evaluated the hamstring complex (“semitendinosus, biceps femoris, and semimembranosus”) ($n = 4$), and only one study assessed the tibialis anterior and the lateral head of gastrocnemius ($n = 1$) [22]. For the placement of surface electrodes, most studies used the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) guidelines for electrode placement.

In relation to EMG tasks, three studies analyzed the electrical activity after dynamic exercises ($n = 3$): (a) single-leg drop landings [54,55]; (b) drop jump [22]. One study used a session based on repeated sprint exercise (RSE) consisting of $20 \times 5''$ sprints on an ergometer ($n = 1$) [47]. Ref. [53] carried out a dynamic power load protocol (10 repetitions at 60%RM with 2 min of rest) to subsequently measure electrical activity ($n = 1$). One study used treadmill running to measure muscle activity, dividing it into several phases: (a) the pre-activation phase, 50 ms before foot landing till foot landing; (b) the weight acceptance phase; and c) the peak push-off phase ($n = 1$) [52]. Finally, Ref. [56] carried out a force steadiness assessment protocol consisting of 4 contractions from 10% to 25% MVC and 2 contractions of 40% MVC (12''–15'' each) ($n = 1$).

Regarding the analysis of muscle activation patterns, the included studies used different EMG-derived variables. One study analyzed RMS, median frequency (MDF), and neuromuscular efficiency (NME) [47]. Two studies assessed muscle onset timing (ms) ($n = 2$) [22,55]. One study evaluated median power frequency as well as variations in %EMG ($n = 1$) [53]. Two studies quantified the normalized measure of %MVC to measure electrical activity (% $\mu V \cdot s$) ($n = 2$) [52,54]. Finally, one study measured the firing rate (Hz) and MUP (motor unit potential) area ($\mu V \cdot ms$) measurements at 10% and 25% of MVC ($n = 1$) [56].

Table 5. Interventions, training status, EMG collection methods, outcomes, and main findings for macroscopic data from surface EMG.

Reference	EMG Collection Method	EMG Outcome	Muscles Recorded	MC Phases	Numerical Values	Main Findings
[47]	3 MVC (5'') with 2'' rest	RMS (mV)	Quadriceps	FP	before RSE (≈ 1.4 mV), after RSE (≈ 0.9 mV)	No significant difference was found between MC phases in all frequency components of EMG before RSE. NME and MDF values of vastus lateralis and rectus femoris were significantly decreased in PMP compared with FP and LP.
				LP	before RSE (≈ 1.3 mV), after RSE (≈ 1.1 Mv)	
				PMP	before RSE (≈ 1.25 mV), after RSE (≈ 1.1 mV)	
		MDF (Hz)	Vastus medialis	FP	before RSE (≈ 88), after RSE (≈ 72)	
				LP	before RSE (≈ 85), after RSE (≈ 69)	
				PMP	before RSE (≈ 84), after RSE (≈ 65)	
			Vastus lateralis	FP	before RSE (≈ 88), after RSE (≈ 79)	
				LP	before RSE (≈ 90), after RSE (≈ 71)	
				PMP	before RSE (≈ 84), after RSE (≈ 60)	
			Rectus femoris	FP	before RSE (≈ 87), after RSE (≈ 72)	
				LP	before RSE (≈ 80), after RSE (≈ 65 mV *)	
				PMP	before RSE (≈ 85), after RSE (≈ 55)	
		NME	Knee extensor muscles	FP	before RSE (≈ 420), after RSE (≈ 505 † *)	
				LP	before RSE (≈ 460 mV), after RSE (≈ 450 mV *)	
				PMP	before RSE (≈ 455 mV), after RSE (≈ 380 mV)	
				† significant difference compared with LP ($p < 0.05$); * significant difference compared with PMP ($p < 0.05$)		
[55]	Single leg drop landings (31 cm box)	Onset timing (ms)	Gluteus medius	EFP	-24.4 ± 63.9	Significant differences were not observed for gluteus medius onset timing ($p = 0.936$) amongst the MC phases. The negative sign (−) represents valgus and EMG onset timing prior to initial contact.
				LFP	-12.8 ± 48.5	
				LP	-28.7 ± 40.3	

Table 5. Cont.

Reference	EMG Collection Method	EMG Outcome	Muscles Recorded	MC Phases	Numerical Values	Main Findings
[22]	3 drop jump (50 cm)	Onset timing (ms)	Gluteus maximus	EFP	-42 ± 50	The semitendinosus exhibited onset delays relative to ground contact during the LP and demonstrated a significant difference between EFP and LFP. Muscle timing differences between the gluteus maximus and semitendinosus were decreased in the LP compared to the EFP.
				LFP	-41 ± 52	
				LP	-56 ± 58	
			Semitendinosus	EFP	-102 ± 19	
				LFP	-97 ± 33	
				LP	-78 ± 17	
			Vastus lateralis	EFP	-87 ± 44	
				LFP	-92 ± 54	
				LP	-95 ± 57	
			Vastus medialis oblique	EFP	-58 ± 30	
				LFP	-57 ± 39	
				LP	-49 ± 37	
			Tibialis anterior	EFP	-104 ± 38	
				LFP	-105 ± 40	
				LP	-99 ± 40	
			Lateral gastrocnemius	EFP	-100 ± 38	
				LFP	-104 ± 29	
				LP	-109 ± 26	

Table 5. Cont.

Reference	EMG Collection Method	EMG Outcome	Muscles Recorded	MC Phases	Numerical Values		Main Findings
[53]	2 sets of 10 reps 60%1 RM (2 min rest between sets) + 3 MVC (isometric) + muscle stimulation	EMG (%)	Vastus lateralis + vastus medialis	M	108.2 ± 13.8	−19.6 ± 12.2	Neither voluntary muscular activity (EMG, MPF) nor electrical stimulation parameters differed between the MC phases before the loading protocol.
				LFP	102.4 ± 10.4	−19.2 ± 14.0	
				OV	97.5 ± 13.3	−14.9 ± 7.6	
				MLP	96.5 ± 10.4	−15.3 ± 11.8	
		MVC (Δ%)		M	−13.7 ± 8.6		
				LPF	−11.7 ± 10.3		
				OV	−7.8 ± 12.2		
				MLP	−15.0 ± 12.3		
		MPF (VL + VM) (Δ%)		M	7.7 ± 24.8		
				LFP	−1.1 ± 19.0		
				OV	−7.5 ± 11.1		
				MLP	3.1 ± 10.6		
[54]	6 Single drop landing (30 cm box)	%MVC (%μV·s) before landing	Gluteus maximus	EFP	9.98 ± 5.22		Activation of the GM in the LP was significantly lower than those in the menstrual and FP. During the MC, there were no significant changes in the activation of the biceps femoris, semitendinosus, or rectus femoris.
				LFP	9.73 ± 5.84		
				OV	8.75 ± 5.19		
				LP	7.75 ± 3.70		
			Biceps femoris	EFP	33.8 ± 33.1		
				LFP	32.2 ± 24.4		
				OV	31.9 ± 30.5		
				LP	40.0 ± 35.1		

Table 5. Cont.

Reference	EMG Collection Method	EMG Outcome	Muscles Recorded	MC Phases	Numerical Values	Main Findings
[54]	6 Single drop landing (30 cm box)	%MVC (% μ V·s) before landing	Semitendinosus	EFP	15.4 ± 11.0	Activation of the GM in the LP was significantly lower than those in the menstrual and FP. During the MC, there were no significant changes in the activation of the biceps femoris, semitendinosus, or rectus femoris.
				LFP	15.3 ± 11.9	
				OV	15.2 ± 11.3	
				LP	16.9 ± 14.3	
			Rectus femoris	EFP	23.8 ± 17.7	
				LFP	23.1 ± 15.6	
				OV	27.3 ± 22.1	
				LP	21.7 ± 24.4	
[52]	6 min running session with 0 inclination at 10 km/h	%MVC	Vastus lateralis	FP	24.26 ± 16.27	Differences in muscle activation strategies during different phases of the MC. The increased quadriceps activity observed during the FP was associated with decreased hamstring activity. Furthermore, the quadriceps and hamstring co-contraction ratios decreased during the EFP compared with the OV.
				OV	12.25 ± 6.63	
			Vastus medialis	FP	24.26 ± 16.27	
				OV	15.84 ± 6.50	
			Lateral hamstrings	FP	31 ± 10.51	
				OV	36.67 ± 12.43	
			Medial hamstrings	FP	25.47 ± 12.50	
				OV	40.45 ± 11.93	
			Vastus lateralis	FP	56.47 ± 14.43	
				OV	34.19 ± 11.96	
			Vastus medialis	FP	44.68 ± 14.89	
				OV	46.51 ± 7.58	
			Lateral hamstrings	FP	36.76	
				OV	61.52 ± 14.52	
			Medial hamstrings	FP	30.43 ± 20.70	
				OV	54.68 ± 16.69	

Table 5. Cont.

Reference	EMG Collection Method	EMG Outcome	Muscles Recorded	MC Phases	Numerical Values		Main Findings
[52]	6 min running session with 0 inclination at 10 km/h	%MVC	Vastus lateralis	FP	Peak push-off phase	14.22 ± 12.44	Differences in muscle activation strategies during different phases of the MC. The increased quadriceps activity observed during the FP was associated with decreased hamstring activity. Furthermore, the quadriceps and hamstring co-contraction ratios decreased during the EFP compared with the OV.
				OV		9.07 ± 7.72	
			Vastus medialis	FP		13.45 ± 5.93	
				OV		11.33 ± 7.65	
			Lateral hamstrings	FP		28.65 ± 14.68	
				OV		18.82 ± 10.17	
			Medial hamstrings	FP		16.96 ± 9.4	
				OV		31.50 ± 21.67	
RMS: root mean square; MDF: median frequency; NME: neuromuscular efficiency; MVC: maximum voluntary contraction; EFP: early follicular phase; OV: ovulation; FP: follicular phase; MLP: mid-luteal phase; LP: luteal phase; RPE: repeated sprint exercise; PMP: premenstrual phase; MPF: mean power frequency; M: menstruation; GM: gluteus maximus; LFP: late-follicular phase; VL: vastus lateralis; VM: vastus medialis.							

Table 6. Interventions, training status, EMG collection methods, outcomes, and main findings for microscopic data from intramuscular EMG.

Reference	EMG Collection Method	Muscles Recorded	EMG Outcome	MC Phases		Numerical Values		Main Findings	
[56]	4 MVC (10%, 25%, 2 × 40%MVC) 12'' – 15'' /each with 30'' rest iEMG	Lateral and medial hamstrings	Firing rate (Hz)	EFP vs. OV		−0.804		Knee extensor MVC did not differ across the menstrual phases ($p > 0.4$). The firing rate of low threshold motor units was lower during the OV and MLP. Motor unit potentials were more complex during OV and MLP ($p < 0.03$). There could be a likely suppression of firing rate early recruited motor units in the OV and MLP.	
				EFP vs. MLP		−0.855			
				OV vs. MLP		−0.051			
			MUPs (μV ms)	EFP vs. OV		70.79			
				EFP vs. MLP		32.19			
				OV vs. MLP		102.9			
			MU FR	EFP	10%MVC	9.77 ± 0.94	25%MVC		No differences across MC phases
				OV		8.94 ± 0.86			
				MLP		8.91 ± 1.01			
			Bold indicates significantly different						
MVC: maximum voluntary contraction; iEMG: intramuscular EMG; MUPs: motor unit potentials; MU FR: motor unit firing rate; EFP: early follicular phase; OV: ovulation; MLP: mid-luteal phase.									

Finally, a critical appraisal of the EMG normalization procedures used in the included studies was conducted to address potential methodological heterogeneity. Most studies normalized EMG amplitude to a percentage of maximal voluntary isometric contraction (%MVIC) [52–54]. Ref. [55] processed the EMG signal with full-wave rectification and low-pass filtering to obtain a linear envelope. However, the authors did not report normalization to a reference contraction, limiting the comparability of EMG amplitudes across subjects or conditions. Similar to this study, in [22], EMG signals were processed with rectification, low-pass filtering, and linear envelope calculation to determine muscle onset and temporal sequencing. Ref. [47] calculated the RMS and MDF of EMG signals over a 500-ms window centered on peak force, and derived the neuromuscular efficiency as the peak force divided by RMS, but no standard EMG normalization procedure was reported. Furthermore, Ref. [56] used intramuscular EMG to assess motor unit activity at 10% and 25% MVC. While the contraction levels were referenced to each participant's MVC, the analysis primarily focused on motor unit properties rather than normalized EMG amplitude.

3.3. Methodological Quality Assessment

3.3.1. Physiological Verification of MC Phases

The a priori assessment of methodological quality classified the studies as being of quality 'moderate' ($n = 6$) and 'high' ($n = 1$), with scores ranging from 10 to 14. However, after applying the two additional questions, two of the moderate studies dropped in quality from moderate to low [22,55]. Only one study had a high quality from the beginning [47]. Figure 2 shows an evolution of scientific quality a priori, after question 1 (Q.1), question 2 (Q.2), and finally the score obtained.

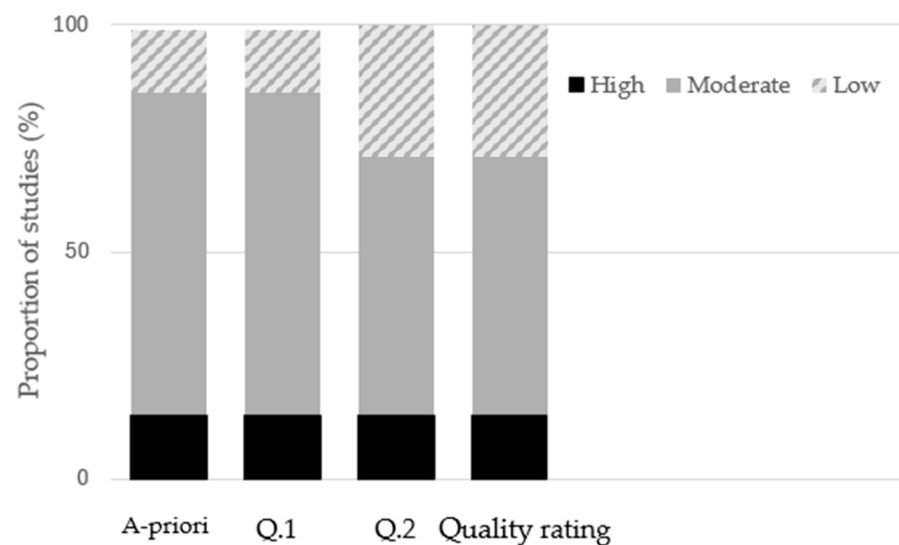


Figure 2. Evolution of the methodological quality after applying the modified Downs and Black checklist.

All articles included in this systematic review verified the phases of the MC using the gold standard method (blood samples) as a mandatory inclusion criterion ($n = 7$). In addition, five studies added urinary tests to confirm ovulation ($n = 5$) [47,52–54,56], one used the basal body temperature method to confirm the duration of the MC ($n = 1$) [55], and one study chose the menstrual diary to verify the absence of pain or discomfort and the duration from the start of menstruation to its return ($n = 1$) [47].

3.3.2. Critical Appraisal Assessment

Results of the quality appraisal of studies using the AXIS tool are presented in Electronic Supplementary Materials File S4: Summary analysis of the quality appraisal of studies using the AXIS tool. The seven studies clearly defined the aim of the study, designed the study appropriately for that stated aim, were measured the outcome variables appropriately and correctly, attained ethical approval, and the methods and statistical significance were sufficiently estimated. Regarding the population under investigation, one study did not define the inclusion and exclusion criteria, and the selection process of two studies was not clearly likely to select subjects (28.57%). Related to the Results section, all studies described the basic data adequately with the results internally consistent, and even the discussion and conclusions were justified by results with the limitations discussed. However, very few studies adjusted the sample size (28.5%) and 57.14% did not undertake measures to address non-responders. Three studies (42.86%) reported that the study was affected by funding sources and two studies without them (28.57%).

3.4. Outcomes

Analysis EMG Outcomes Between Menstrual Cycle Phases

Studies with significant differences between menstrual cycle phases [22] found a delay in the onset timing of the semitendinosus muscle in the LP ($p = 0.002$) of the MC compared to the EFP ($p = 0.001$) and LFP ($p = 0.02$). These authors also found that hip electrical activity values were altered by the MC. Post hoc results revealed that the difference in onset timing between the gluteus maximus and semitendinosus was significantly lower in the LP compared to the EFP.

Comparing the study that evaluated electrical activity expressed in %MVC, we found that gluteus maximus activation (150 ms before landing) was significantly lower in the LP compared to the follicular and menstrual phases ($p < 0.05$) [54].

Last but not least, Ref. [52] found that the quadriceps exhibited an increase in electrical activity during the EFP compared to OV in the pre-contact and weight acceptance phases of running ($p = 0.02, 0.04$, respectively). For the vastus lateralis, a significant increase was observed during the FP compared to the OV ($p = 0.014$). Regarding hamstring activity, the OV altered hamstring pre-activity before impact. The mean peak of hamstring electrical activity during the pre-contact and weight acceptance phase was significantly higher during OV compared to the EFP. This increased hamstring activity was also observed during weight acceptance, with increased EMG amplitude ($p < 0.001$). Notably, quadriceps–hamstring co-contraction was significantly greater compared to the FP ($p < 0.001$).

Studies with no significant differences between menstrual cycle phases [47] found no significant interaction between the MC phases $\times$ RSE for RMS values ($F(2,18) = 1.88, p > 0.05$). The post hoc test revealed that all RMS values decreased significantly after RSE in all MC phases ($p < 0.05$, for all phases). Regarding neuromuscular efficiency, a significant interaction was found between phase $\times$ RSE ($F(2,18) = 10.92, p < 0.05$). The post hoc test revealed that the neuromuscular efficiency values were significantly lower during the PP compared to the FP and LP after RSE ($p < 0.05$). However, neuromuscular efficiency values increased significantly after exercise only during the FP ($p < 0.01$). In terms of MDF, the vastus lateralis and rectus femoris muscles showed significant phase $\times$ RSE interaction ($F(2,18) = 4.72, p < 0.05$). After RSE, all MDF values decreased, with this decrease being more pronounced in the PP compared to the LP and FP ($p < 0.05$). Moreover, no significant differences were found between MC phases in all frequency components of EMG before RSE ($p > 0.05$).

According to the study by [56], at 10% MVC, a lower firing rate was revealed at OV and in the LP compared to the EFP ($p < 0.001$). No differences were found between OV

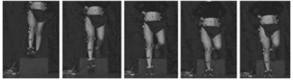
and the MLP ($p = 0.792$). On the other hand, at 25%MVC, the firing rate of motor neurons did not vary between phases of the MC ($p > 0.3$). Likewise, no statistically significant differences in firing rate were found in the EFP. However, the firing rate increased from 10% to 25% MVC at OV ($p = 0.047$) and in the MLP ($p = 0.0015$). A significant level $\times$ time interaction was found when comparing the EFP with OV ($p = 0.09$) and the MLP ($p = 0.009$), indicating a longer contraction.

In relation to the two studies that used onset timing (ms) to analyze electrical activity between MC phases [22,55], only Ref. [55] found no significant differences in the onset timing of the gluteus medius ($p = 0.936$) between MC phases during the single leg drop landing exercise.

Although the study by [54] found significant changes in the gluteus maximus, no changes were found in the activation of the biceps femoris, semitendinosus, and rectus femoris between phases of the MC. Finally, Ref. [53] found no differences in the voluntary muscle activity (EMG, MPF) or in the electrically stimulated parameters prior to the loading protocol.

Table 7 summarizes the findings of the seven articles included in the review regarding task categories and effects.

Table 7. Analysis EMG studies about muscle activation patterns during MC phases; * study showing significant differences and no differences in muscle activation patterns depending on musculature.

Study	Task Type	Differences Effects	Null Effects	Comments
[47]	 RSE session. Fatiguing protocol		✗	No significant difference was found between MC phases in all frequency components of EMG before RSE.
[53]	 Dynamic protocol		✗	Differences in performance parameters in the unfatigued condition were not observed between MC phases.
[56]	 Isometric protocol		✗	Assessment of neuromuscular performance did not differ across MC.
[55]	 Single-leg drop landing		✗	EMG onset timing of gluteus medius muscle differences were not observed throughout the MC phases.
[54]	 Single drop landing	✓	✗	During MC, there were no significant changes in the activation of biceps femoris, semitendinosus, or rectus femoris. * Activation of the gluteus medius in the LP was significantly lower than those in the menstrual phase and FP. *
[22]	 Drop jump	✓		Female recreational athletes utilize different neuromuscular control pattern for performing a drop jump when estrogen levels are high (luteal phase).
[52]	 Running	✓		Differences in muscle activation strategies during MC phases.

✗ = not significant difference in muscle activation between MC phases; ✓ = significant difference in muscle activation between MC phases.

4. Discussion

The main aim of this systematic review was to determine whether muscle activation patterns differed across MC phases in eumenorrheic women. Overall, the methodological quality of the included studies was moderate, which, together with the heterogeneity in testing protocols and EMG outcomes, contributes to the variability observed in the results. Furthermore, the marked heterogeneity in MC phase definitions represents an important methodological limitation within the current evidence base. Although all included studies verified with blood hormone analysis, inconsistencies in phase delineation (e.g., OV timing, MLP confirmation, FP subdivision criteria) may contribute to between-study variability and partially explain the conflicting findings. Greater standardization in phase classification criteria is needed to improve comparability, reproducibility, and the overall interpretability of research in this field.

This review included seven studies [22,47,52–56], and the discussion was structured around the tasks performed and the EMG variables analyzed.

A critical finding across several studies was the alteration of proximal stabilization strategies, particularly during the LP compared to EFP. In particular, reduced gluteus maximus activation and delayed onset timing [22,54] suggest a potential compromise in the ability to resist knee valgus moments during dynamic tasks like drop landings. This shift toward a “knee-based” activation pattern, characterized by increased quadriceps reliance and decreased hamstring activity during FP, may increase anterior tibial translation. Furthermore, the quadriceps and hamstring co-contraction ratios decreased during the EFP compared with the OV [52]. Rather than viewing these changes in isolation, they should be interpreted as a shift in feed-forward control strategies.

The coordination between the gluteus maximus and semitendinosus is essential for controlling the torsional motions of the femur and tibia [57]. Therefore, the subtle delays in muscle onset reported in the LP may reflect a modified neuromuscular “template” that may potentially heighten the risk of non-contact anterior cruciate ligament (ACL) injuries. However, due to the small sample and task heterogeneity, it is important to note that ACL injury mechanisms are multifactorial and remain inconclusive. Injuries are likely influenced by a more complex and indirect injury mechanism that incorporates hormonal fluctuations and the dynamic function of the knee joint, which may be specific to each individual.

The impact of the MC on the EMG signal appears to be further magnified under neuromuscular fatigue or high-intensity loading. In non-fatigued or submaximal conditions, phase differences are often negligible [53]. However, when fatiguing protocols are introduced, particularly during the late-luteal phase or premenstrual phases, there is a documented decrease in MDF and nerve conduction velocity [47,58,59]. This suggests that the lowest levels of ovarian hormones may limit the neuromuscular system’s resilience to exhaustion. Furthermore, motor unit firing patterns exhibit a contraction-level dependency. The observation that firing rates in the vastus lateralis are highest during the EFP only at low intensities (10% MVC) [56] indicates that hormonal modulation of the motor neuron pool might be bypassed or overridden during higher force outputs. This highlights a narrow window of influence where hormonal shifts primarily affect fine motor control or fatigued states rather than maximal voluntary strength. These results only partially align with those of [60], who reported increased firing rates across phases using basal body temperature for MC identification, highlighting again how methodological approaches can shape outcomes.

All results presented in this systematic review should be interpreted with caution due to significant differences in the methodologies used, such as (1) the difficulty of evaluating prospective studies relating to more than one MC; (2) the level of participation in sport among women; (3) dynamic exercises vs. static exercises; (4) fatigued conditions vs. non-

fatigued conditions; (5) different methods of verifying the MC; and (6) different ways of normalizing the EMG signal and coding it.

Overall, the evidence reviewed does not support a consistent or global effect of MC phases on muscle activation patterns. Instead, the findings suggest that any hormonal influence is highly task-dependent and muscle-specific. Differences tend to emerge only under conditions of high neuromuscular demand such as rapid deceleration, landing, or fatiguing protocols, whereas submaximal or controlled voluntary tasks show minimal or no modulation across the cycle.

Across several studies, the LP could be associated with subtle alterations in neuromuscular timing, particularly delayed or reduced gluteus maximus activity and changes in hamstring onset patterns. These findings, although not uniform, point toward a potential shift in feed-forward control strategies during phases of higher progesterone concentration. Such alterations may compromise the ability to stabilize the hip and knee during dynamic movements, aligning with observations of increased joint laxity and reduced stiffness reported in other physiological literature.

From a mechanistic perspective, hormonal fluctuations may influence neuromuscular performance through changes in connective tissue compliance, proprioceptive feedback, or motor-unit recruitment strategies. Elevated estrogen levels, for example, have been associated with increased ligamentous laxity and reduced collagen stiffness, potentially requiring compensatory neuromuscular adjustments. These physiological mechanisms may help explain phase-specific differences in muscles critical for hip and knee stabilization during high-intensity movements. However, despite these hormonally driven variations in laxity or stiffness, current evidence indicates that the mechanical properties of the ligament itself remain sufficiently preserved to maintain its mechanoreceptive function, ensuring that proprioceptive input and joint position sense are not structurally compromised across menstrual cycle phases.

Last, but not least, we must emphasize that most findings came from small, single-cycle, underpowered studies, which limit the strength of inference about injury risk or training prescription.

4.1. Practical Application

It remains unclear whether hormonal fluctuations across the MC exert a consistent influence on muscle activation patterns in eumenorrheic women. While women are reported to have a 4- to 6-fold greater risk of sustaining knee injuries, such as ACL ruptures, compared to men [61], the link between these injuries and specific menstrual phases remains a subject of ongoing debate. Given the high degree of individual variability and the current uncertainty in the literature, any adjustments to training loads based on physiological or hormonal changes should be viewed as exploratory rather than evidence-based protocols.

As highlighted by [62,63], neuromuscular training that replicates the dynamic loads experienced in sports can enhance both anticipatory and reactive muscle activation strategies. These adaptations are crucial for improving joint protection and optimizing force distribution.

Therefore, the findings of this systematic review may serve as a hypothesis-generating framework for professionals in physical activity and sport sciences. Rather than prescribing rigid interventions, coaches and trainers might consider the MC as one of many variables in a personalized approach. Acknowledging that some athletes may exhibit task-dependent alterations in neuromuscular activation could help in designing highly individualized monitoring strategies, though further robust evidence is required to confirm whether phase-specific adjustments effectively minimize injury susceptibility.

4.2. Study Limitations and Strengths

Our study was limited by the scarcity of scientific evidence on the influence of MC phases on muscle activation patterns in eumenorrheic women. Furthermore, one of the main limitations of the studies analyzed was the wide disparity in the methodology used to verify MC phases and in the way the EMG signal was coded (measurement protocols). A major strength of this review is the inclusion of only studies that verified MC phases through blood hormone analysis, ensuring accurate phase classification and high internal validity. Although this rigorous criterion reduced the number of eligible studies, it represents a deliberate trade-off favoring methodological quality over broader coverage. These results show the significant impact of hormonal fluctuations on markers such as athletic performance and/or health and, therefore, the need to continue including new lines of scientific research that include the MC as a monitoring variable with the aim of improving health and well-being in the female population.

5. Conclusions

While some studies show that changes in serum progesterone and estrogen levels may decrease the stability of certain joints and impair muscle balance and coordination, most studies concluded that muscle activation patterns appear to be unaffected by the phases of the MC. It is true that alterations in semitendinosus muscle onset and muscle onset timing appear to occur when estrogen levels are high.

However, further research is needed to investigate the role of hormonal fluctuations on neuromuscular control patterns during dynamic movements (cutting maneuvers, single drop jump, countermovement jump, etc.) to mimic a sporting environment and determine whether the muscle activation patterns occur due to alterations in the force transmission properties of passive tissues or centrally driven mechanisms or depend on estrogen level.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app16052579/s1>, File S1: Search strategy and MeSH; File S2: Quality appraisal for physiological verification—modified Downs and Black checklist; File S3: Quality appraisal—AXIS TOOL; File S4: Summary analysis of the quality appraisal of studies using the AXIS tool.

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Abbreviations

The following abbreviations are used in this manuscript:

MC	Menstrual Cycle
M	Menstruation
FP	Follicular Phase
OV	Ovulation

LP	Luteal Phase
EFP	Early Follicular Phase
LFP	Late Follicular Phase
MP	Menstruation Phase
MVC	Maximum Voluntary Contraction
EMG	Electromyography
RMS	Root Mean Square
OC	Oral Contraceptive
RSE	Repeated Sprint Exercise
MUP	Motor Unit Potentials
PP	Premenstrual Phase
MLP	Mid-Luteal Phase
MDF	Median Frequency
NME	Neuromuscular Efficiency
AL	Voluntary Activation
ACL	Anterior Cruciate Ligament

References

1. European Commission. Gender Equality in Sport: Proposal for Strategic Actions 2014–2020. Available online: https://ec.europa.eu/assets/eac/sport/events/2013/documents/20131203-gender/final-proposal-1802_en.pdf (accessed on 28 May 2019).
2. Fink, J.S. Female athletes, women's sport, and the sport media commercial complex: Have we really “come a long way, baby”? *Sport Manag. Rev.* **2014**, *18*, 331–342. [CrossRef]
3. Landen, S.; Hiam, D.; Voisin, S.; Jacques, M.; Lamon, S.; Eynon, N. Physiological and molecular sex differences in human skeletal muscle in response to exercise training. *J. Physiol.* **2023**, *601*, 419–434. [CrossRef] [PubMed]
4. Thompson, B.M.; Drover, K.B.; Stellmaker, R.J.; Sculley, D.V.; Janse de Jonge, X.A.K. The effect of the menstrual cycle and oral contraceptive cycle on muscle performance and perceptual measures. *Int. J. Environ. Res. Public Health* **2021**, *18*, 10565. [CrossRef] [PubMed]
5. Dawson, E.; Reilly, T. Menstrual cycle, exercise and health. *Biol. Rhythm. Res.* **2009**, *40*, 99–119. [CrossRef]
6. de Jonge, X.J.; Thompson, B.; Ahreum, H.A.N. Methodological Recommendations for Menstrual Cycle Research in Sports and Exercise. *Med. Sci. Sports Exerc.* **2019**, *51*, 2610–2617. [CrossRef]
7. McNulty, K.L.; Elliott-Sale, K.J.; Dolan, E.; Swinton, P.A.; Ansdell, P.; Goodall, S.; Thomas, K.; Hicks, K.M. The Effects of Menstrual Cycle Phase on Exercise Performance in Eumenorrheic Women: A Systematic Review and Meta-Analysis. *Sports Med.* **2020**, *50*, 1813–1827. [CrossRef]
8. Ansdell, P.; Brownstein, C.G.; Skarabot, J.; Hicks, K.M.; Simoes, D.C.M.; Thomas, K.; Howatson, G.; Hunter, S.K.; Goodall, S. Menstrual cycle-associated modulations in neuromuscular function and fatigability of the knee extensors in eumenorrheic women. *J. Appl. Physiol.* **2019**, *126*, 1701–1712. [CrossRef]
9. Blagrove, R.C.; Bruinvels, G.; Pedlar, C.R. Variations in strength-related measures during the menstrual cycle in eumenorrheic women: A systematic review and meta-analysis. *J. Sci. Med. Sport* **2020**, *23*, 1220–1227. [CrossRef]
10. Florini, J.R. Hormonal control of muscle growth. *Muscle Nerve* **1987**, *10*, 577–598. [CrossRef]
11. Deters, J.R.; Fietsam, A.C.; Workman, C.D.; Rudroff, T. High Estrogen Levels Cause Greater Leg Muscle Fatigability in Eumenorrheic Young Women after 4 mA Transcranial Direct Current Stimulation. *Brain Sci.* **2022**, *12*, 506. [CrossRef]
12. Bencke, J.; Aagaard, P.; Zebis, M.K. Muscle activation during ACL injury risk movements in young female athletes: A narrative review. *Front. Physiol.* **2018**, *9*, 445. [CrossRef]
13. Oosthuysen, T.; Bosch, A.N. The Effect of the Menstrual Cycle on Exercise Metabolism. *Sports Med.* **2010**, *40*, 207–227. [CrossRef] [PubMed]
14. Constantini, N.W.; Dubnov, G.; Lebrun, C.M. The menstrual cycle and sport performance. *Clin. Sports Med.* **2005**, *24*, 51–82. [CrossRef]
15. Hewett, T.E. Neuromuscular and hormonal factors associated with knee injuries in female athletes. Strategies for intervention. *Sports Med. (Auckland N.Z.)* **2000**, *29*, 313–327. [CrossRef]
16. Hansen, M. Female hormones: Do they influence muscle and tendon protein metabolism? *Proc. Nutr. Soc.* **2018**, *77*, 32–41. [CrossRef]
17. Bennal, A.S.; Chavan, V. Nerve Conduction Velocity across the phases of menstrual cycle. *Indian J. Clin. Anat. Physiol.* **2017**, *4*, 1–3.
18. McClung, J.M.; Davis, J.M.; Wilson, M.A.; Goldsmith, E.C.; Carson, J.A. Estrogen status and skeletal muscle recovery from disuse atrophy. *J. Appl. Physiol.* **2006**, *100*, 2012–2023. [CrossRef]

19. Wentorf, F.A.; Sudoh, K.; Moses, C.; Arendt, E.A.; Carlson, C.S. The effects of estrogen on material and mechanical properties of the intra- and extra-articular knee structures. *Am. J. Sports Med.* **2006**, *34*, 1948–1952. [\[CrossRef\]](#)
20. Bailey, S.P.; Zacher, C.M.; Mittleman, K.D. Effect of menstrual cycle phase on carbohydrate supplementation during prolonged exercise to fatigue. *J. Appl. Physiol. (Bethesda Md. 1985)* **2000**, *88*, 690–697. [\[CrossRef\]](#) [\[PubMed\]](#)
21. Iwamoto, Y.; Kubo, J.; Ito, M.; Takemiya, T.; Asami, T. Variation in maximal voluntary contraction during the menstrual cycle. *Jpn. J. Phys. Fit. Sports Med.* **2002**, *51*, 193–201. [\[CrossRef\]](#)
22. Dedrick, G.S.; Sizer, P.S.; Merkle, J.N.; Hounshell, T.R.; Robert-McComb, J.J.; Sawyer, S.F.; Brismée, J.M.; Roger James, C. Effect of sex hormones on neuromuscular control patterns during landing. *J. Electromyogr. Kinesiol.* **2008**, *18*, 68–78. [\[CrossRef\]](#)
23. Prado-Álvarez, R.; Estrada-barranco, C.; González-de-la-flor, Á.; De, M.; San, P.; Almazán-Polo, J.; Guerineau, F.; Giménez, M. Endurance and electromyographic assessment of abdominopelvic motor control in women with primary dysmenorrhea: A cross-sectional study. *Sci. Rep.* **2024**, *14*, 28836. [\[CrossRef\]](#)
24. Romero-Moraleda, B.; Del Coso, J.; Gutiérrez-Hellín, J.; Ruiz-Moreno, C.; Grgic, J.; Lara, B. The influence of the menstrual cycle on muscle strength and power performance. *J. Hum. Kinet.* **2019**, *68*, 123–133. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Romero-Moraleda, B.; Morencos-Martínez, E.; Varón, P.; Lara, B.; Jiménez-Ormeño, E.; Peinado, A.B.; González-García, J. The influence of menstrual cycle phase on neuromuscular performance and subjective perception of effort in elite football players. *Biol. Sport* **2025**, *42*, 89–98. [\[CrossRef\]](#)
26. Costa Pde, L.; Santos, F.P.; Rocha, C.C.D.; Da Silva, S.F. Study on the electromyographic activation of lower limbs during the menstrual cycle phases. *J. Exerc. Physiol. Online* **2015**, *18*, 52–57.
27. Janse De Jonge, X.A.K.; Boot, C.R.L.; Thom, J.M.; Ruell, P.A.; Thompson, M.W. The influence of menstrual cycle phase on skeletal muscle contractile characteristics in humans. *J. Physiol.* **2001**, *530*, 161–166. [\[CrossRef\]](#)
28. Kubo, K.; Miyamoto, M.; Tanaka, S.; Maki, A.; Tsunoda, N.; Kanehisa, H. Muscle and tendon properties during menstrual cycle. *Int. J. Sports Med.* **2009**, *30*, 139–143. [\[CrossRef\]](#)
29. Samani, M.; Kordi Yoosefinejad, A.; Campos, M.H.; de Lira, C.A.B.; Motealleh, A. Changes in Knee Vastii Muscle Activity in Women with Patellofemoral Pain Syndrome During the Menstrual Cycle. *PM&R* **2020**, *12*, 382–390. [\[CrossRef\]](#)
30. Pereira, H.M.; Larson, R.D.; Bembien, D.A. Menstrual Cycle Effects on Exercise-Induced Fatigability. *Front. Physiol.* **2020**, *11*, 517. [\[CrossRef\]](#) [\[PubMed\]](#)
31. Kavanagh, J.J.; McFarland, A.J.; Taylor, J.L. Enhanced availability of serotonin increases activation of unfatigued muscle but exacerbates central fatigue during prolonged sustained contractions. *J. Physiol.* **2019**, *597*, 319–332. [\[CrossRef\]](#)
32. Cordeiro, L.M.S.; Rabelo, P.C.R.; Moraes, M.M.; Teixeira-Coelho, F.; Coimbra, C.C.; Wanner, S.P.; Soares, D.D. Physical exercise-induced fatigue: The role of serotonergic and dopaminergic systems. *Braz. J. Med. Biol. Res. Rev. Bras. De Pesqui. Medicas E Biol.* **2017**, *50*, e6432. [\[CrossRef\]](#)
33. Balachandar, V.; Marciniak, J.L.; Wall, O.; Balachandar, C. Effects of the menstrual cycle on lower-limb biomechanics, neuromuscular control, and anterior cruciate ligament injury risk: A systematic review. *Muscles Ligaments Tendons J.* **2017**, *7*, 136–146. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Shultz, S.J.; Schmitz, R.J.; Kong, Y.; Dudley, W.N.; Beynnon, B.D.; Nguyen, A.D.; Kim, H.; Montgomery, M.M. Cyclic variations in multiplanar knee laxity influence landing biomechanics. *Med. Sci. Sports Exerc.* **2012**, *44*, 900–909. [\[CrossRef\]](#) [\[PubMed\]](#)
35. Belanger, M.J.; Moore, D.C.; Crisco, J.J., 3rd; Fadale, P.D.; Hulstyn, M.J.; Ehrlich, M.G. Knee laxity does not vary with the menstrual cycle, before or after exercise. *Am. J. Sports Med.* **2004**, *32*, 1150–1157. [\[CrossRef\]](#)
36. Stijak, L.; Kadija, M.; Djulejic, V.; Aksic, M.; Petronijevic, N.; Markovic, B.; Radonjic, V.; Bumbasirevic, M.; Filipovic, B. The influence of sex hormones on anterior cruciate ligament rupture: Female study. *Knee Surg. Sports Traumatol. Arthrosc.* **2015**, *23*, 2742–2749. [\[CrossRef\]](#)
37. Bencke, J.; Zebis, M.K. The influence of gender on neuromuscular pre-activity during side-cutting. *J. Electromyogr. Kinesiol.* **2011**, *21*, 371–375. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Chappell, J.D.; Creighton, R.A.; Giuliani, C.; Yu, B.; Garrett, W.E. Kinematics and electromyography of landing preparation in vertical stop-jump: Risks for noncontact anterior cruciate ligament injury. *Am. J. Sports Med.* **2007**, *35*, 235–241. [\[CrossRef\]](#)
39. Nagano, Y.; Ida, H.; Akai, M.; Fukubayashi, T. Gender differences in knee kinematics and muscle activity during single limb drop landing. *Knee* **2007**, *14*, 218–223. [\[CrossRef\]](#)
40. Pollard, C.D.; Sigward, S.M.; Powers, C.M. Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clin. Biomech.* **2010**, *25*, 142–146. [\[CrossRef\]](#)
41. Schultz, K.N.; Von Esenwein, S.A.; Hu, M.; Bennett, A.L.; Kennedy, R.T.; Musatov, S.; Toran-Allerand, C.D.; Kaplitt, M.G.; Young, L.J.; Becker, J.B. Viral vector-mediated overexpression of estrogen receptor- α in striatum enhances the estradiol-induced motor activity in female rats and estradiol-modulated GABA release. *J. Neurosci.* **2009**, *29*, 1897–1903. [\[CrossRef\]](#)
42. Zazulak, B.T.; Ponce, P.L.; Straub, S.J.; Medvecky, M.J.; Avedisian, L.; Hewett, T.E. Gender comparison of hip muscle activity during single-leg landing. *J. Orthop. Sports Phys. Ther.* **2005**, *35*, 292–299. [\[CrossRef\]](#)

43. Sharma, M.; Singh, A. Gender differences in muscle activation patterns during squat and countermovement jumps in soccer players. *J. Phys. Educ. Sport* **2024**, *24*, 2017–2024. [\[CrossRef\]](#)
44. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ (Clin. Res. Ed.)* **2021**, *372*, n71. [\[CrossRef\]](#)
45. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Antes, G.; Atkins, D.; Barbour, V.; Barrowman, N.; Berlin, J.A.; Clark, J.; et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*, e1000097. [\[CrossRef\]](#)
46. Fehring, R.J.; Schneider, M.; Raviele, K. Variability in the phases of the menstrual cycle. *J. Obstet. Gynecol. Neonatal Nurs. JOGNN* **2006**, *35*, 376–384. [\[CrossRef\]](#)
47. Graja, A.; Kacem, M.; Hammouda, O.; Borji, R.; Bouzid, M.A.; Souissi, N.; Rebai, H. Physical, Biochemical, and Neuromuscular Responses to Repeated Sprint Exercise in Eumenorrheic Female Handball Players: Effect of Menstrual Cycle Phases. *J. Strength Cond. Res.* **2022**, *36*, 2268–2276. [\[CrossRef\]](#)
48. Ouzzani, M.; Hammady, H.; Fedorowicz, Z.; Elmagarmid, A. Rayyan—A web and mobile app for systematic reviews. *Syst. Rev.* **2016**, *5*, 210. [\[CrossRef\]](#) [\[PubMed\]](#)
49. Downs, S.H.; Black, N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J. Epidemiol. Community Health* **1998**, *52*, 377–384. [\[CrossRef\]](#)
50. Niering, M.; Wolf-Belala, N.; Seifert, J.; Tovar, O.; Coldewey, J.; Kuranda, J.; Muehlbauer, T. The Influence of Menstrual Cycle Phases on Maximal Strength Performance in Healthy Female Adults: A Systematic Review with Meta-Analysis. *Sports* **2024**, *12*, 31. [\[CrossRef\]](#) [\[PubMed\]](#)
51. Dos’Santos, T.; Stebbings, G.K.; Morse, C.; Shashidharan, M.; Daniels, K.A.J.; Sanderson, A. Effects of the menstrual cycle phase on anterior cruciate ligament neuromuscular and biomechanical injury risk surrogates in eumenorrheic and naturally menstruating women: A systematic review. *PLoS ONE* **2023**, *18*, e0280800. [\[CrossRef\]](#) [\[PubMed\]](#)
52. Khowailed, I.A.; Petrofsky, J.; Lohman, E.; Daher, N.; Mohamed, O. 17 β -Estradiol Induced Effects on Anterior Cruciate Ligament Laxness and Neuromuscular Activation Patterns in Female Runners. *J. Women’s Health* **2015**, *24*, 670–680. [\[CrossRef\]](#)
53. Peltonen, H.; Mikkonen-Taipale, R.; Uimonen, T.; Walker, S.; Hackney, A.C.; Valtonen, M.; Kyröläinen, H.; Ihalaenen, J.K. Power Loading-Induced Fatigue Is Influenced by Menstrual Cycle Phase. *Med. Sci. Sports Exerc.* **2022**, *54*, 1190–1198. [\[CrossRef\]](#)
54. Okazaki, M.; Kaneko, M.; Ishida, Y.; Murase, N.; Katsumura, T. Changes in the Width of the Tibiofibular Syndesmosis Related to Lower Extremity Joint Dynamics and Neuromuscular Coordination on Drop Landing During the Menstrual Cycle. *Orthop. J. Sports Med.* **2017**, *5*, 2325967117724753. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Cesar, G.M.; Pereira, V.S.; Santiago, P.R.P.; Benze, B.G.; da Costa, P.H.L.; Amorim, C.F.; Serrão, F.V. Variations in dynamic knee valgus and gluteus medius onset timing in non-athletic females related to hormonal changes during the menstrual cycle. *Knee* **2011**, *18*, 224–230. [\[CrossRef\]](#)
56. Piasecki, J.; Guo, Y.; Jones, E.J.; Phillips, B.E.; Stashuk, D.W.; Atherton, P.J.; Piasecki, M. Menstrual Cycle Associated Alteration of Vastus Lateralis Motor Unit Function. *Sports Med. Open* **2023**, *9*, 97. [\[CrossRef\]](#)
57. McLean, S.G.; Huang, X.; van der Bogert, A.J. Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: Implications for ACL injury. *Clin. Biomech.* **2005**, *20*, 863–870. [\[CrossRef\]](#) [\[PubMed\]](#)
58. Soares, F.A.; Salomoni, S.E.; Veneziano, W.H.; de Carvalho, J.L.; Nascimento, F.A.; Pires, K.F.; da Rocha, A.F. On the behavior of surface electromyographic variables during the menstrual cycle. *Physiol. Meas.* **2011**, *32*, 543–557. [\[CrossRef\]](#) [\[PubMed\]](#)
59. Salomoni, S.; Soares, F.A.; de Oliveira Nascimento, F.A.; da Rocha, A.F. Gender differences in muscle fatigue of the biceps brachii and influences of female menstrual cycle in electromyography variables. In Proceedings of the 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Vancouver, BC, Canada, 20–25 August 2008; pp. 2598–2601. [\[CrossRef\]](#)
60. Tenan, M.S.; Peng, Y.L.; Hackney, A.C.; Griffin, L. Menstrual cycle mediates vastus medialis and vastus medialis oblique muscle activity. *Med. Sci. Sports Exerc.* **2013**, *45*, 2151–2157. [\[CrossRef\]](#) [\[PubMed\]](#)
61. Hewett, T.E.; Zazulak, B.T.; Myer, G.D. Effects of the menstrual cycle on anterior cruciate ligament injury risk: A systematic review. *Am. J. Sports Med.* **2007**, *35*, 659–668. [\[CrossRef\]](#)
62. Lebrun, C.M. The effect of the phase of the menstrual cycle and the birth control pill on athletic performance. *Clin. Sports Med.* **1994**, *13*, 419–441. [\[CrossRef\]](#)
63. Wojtyś, E.M.; Huston, L.J. Neuromuscular performance in normal and anterior cruciate ligament-deficient lower extremities. *Am. J. Sports Med.* **1994**, *22*, 89–104. [\[CrossRef\]](#) [\[PubMed\]](#)

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