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Concurrent training in women: Hormonal responses, adaptation interference, and health-based optimization strategies

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Abstract

Background: Concurrent training, defined as the combination of endurance and resistance exercises within a short time frame, has recently gained significant attention in women due to its relevance for performance, health, and body composition. However, the unique hormonal characteristics of women may influence physiological adaptive responses and potentially modulate the degree of interference between strength and endurance adaptations.

Methods: This paper presents a narrative review with a systematic approach, conducted in accordance with the PRISMA 2020 guidelines. A systematic search of PubMed, Scopus, Web of Science, and Google Scholar was performed from each database's inception until January 2025. English-language studies were included if they investigated concurrent resistance and endurance training in women, including randomized controlled trials, interventional studies, and observational studies reporting outcomes related to strength, endurance, hormonal responses, or interference effects. Studies focusing exclusively on hydration, nutrient timing, or unrelated performance modifiers were excluded. A total of 55 studies met the inclusion criteria. Due to methodological heterogeneity, meta-analysis was not feasible; therefore, findings were synthesized narratively across three predefined domains. Certainty of evidence was assessed using the GRADE framework.

Results: Across the included studies (n = 55), evidence of moderate certainty suggests that estrogen may attenuate muscle damage and modulate interference effects on strength adaptations, particularly in the follicular phase. However, evidence regarding luteal-phase recovery and progesterone-mediated effects remains limited and of low certainty. Endurance-dominant sequencing appears to increase AMPK activation, potentially inhibiting mTOR signaling, although findings are inconsistent. Overall, hormonal fluctuations may partially explain sex-specific responses to concurrent training.

Conclusion: Due to sex-specific physiological and hormonal characteristics, women exhibit distinct responses to concurrent training. Targeted manipulation of training variables according to menstrual cycle phase and the reduction of conflicting molecular signaling can mitigate interference effects and enhance performance.

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Highlights

What is current knowledge?

- Concurrent training can simultaneously improve muscular strength, endurance performance, and body composition in women.
- The interference effect between resistance and endurance training is influenced by exercise sequence, training intensity, recovery intervals, and individual physiological characteristics.
- Hormonal fluctuations across the menstrual cycle may affect neuromuscular adaptation, recovery, substrate utilization, and molecular signaling pathways related to concurrent training.

What is new here?

- This review provides a comprehensive female-specific synthesis of concurrent training studies published between 2020 and 2025.
- Current evidence suggests that women may experience a smaller degree of concurrent training interference compared with men, potentially due to estrogen-related protective mechanisms.
- Menstrual cycle phase and hormonal status may influence AMPK-mTOR signaling, recovery responses, and adaptation to concurrent training.
- Resistance-first sequencing, appropriate session spacing, and menstrual cycle-aware programming may help optimize concurrent training adaptations in women.

Introduction

Concurrent training (CT), defined as the simultaneous integration of resistance and endurance exercises within a single training program, has emerged in recent decades as a widely used strategy to enhance multiple components of physical fitness, improve body composition, and promote overall health (1,2). Unlike single-mode training programs that focus exclusively on maximal strength or high levels of endurance, many sports require athletes to develop a combination of both capacities. Consequently, CT is recommended to simultaneously optimize strength and endurance adaptations, providing athletes with functional performance improvements applicable across a wide range of disciplines (1,2). While the literature on CT is extensive, the vast majority of studies have been conducted in male populations, and only a limited number have addressed female-specific physiological factors that may influence training responses, such as hormonal fluctuations across the menstrual cycle, menstrual dysfunction, or the use of hormonal contraceptives (1,3). These factors can influence both acute exercise responses and long-term adaptations, highlighting the importance of sex-specific investigations when designing CT programs for women (1,3). The concept of the "interference effect," initially described by Hickson, refers to the attenuation of strength and hypertrophy adaptations that occurs when resistance and endurance exercises are performed concurrently (4,5). Mechanistically, this phenomenon has been attributed to interactions among molecular signaling pathways, differential energy demands, and acute or chronic neuromuscular fatigue (4,6). In women, these interactions may be further modulated by hormonal status. Estrogen, for instance, is thought to exert protective effects on skeletal muscle by enhancing recovery, reducing exercise-induced muscle damage, and supporting satellite cell activity, which is critical for muscle repair and hypertrophy (7-10). Additionally, the luteal phase of the menstrual cycle may influence energy metabolism, recovery rates, and susceptibility to fatigue, potentially affecting the magnitude of adaptations achieved through CT (7-10). These hormonal mechanisms may partly explain why CT-induced interference appears less pronounced in women compared to men (2,5,7). Despite these insights, empirical evidence directly investigating sex-specific hormonal modulation of CT adaptations remains limited, and further research is needed to clarify these relationships. A systematic review of CT studies conducted in healthy adult women revealed that only a small fraction of trials included female participants aged 18-50 years with training interventions lasting at least eight weeks (1). These studies generally reported improvements in both strength- and endurance-related outcomes, alongside beneficial changes in body composition and blood lipid profiles. However, none of the included studies specifically examined the interference effect in women, and single-modality training groups were inconsistently included for comparison (1,2). Notably, critical performance variables such as rapid force production, which reflects the neuromuscular system's ability to generate force quickly, were seldom assessed, and hormonal influences were rarely controlled or reported (1,3). This gap in knowledge limits the capacity to fully understand how female-specific factors modulate CT adaptations and underscores the need for more targeted research in women. Training variables, including exercise modality, volume, intensity, program duration, and session sequencing, are known to significantly influence both acute responses and long-term adaptations in CT (4,6,11). In female athletes, these variables interact with menstrual cycle phases, producing distinct muscular, metabolic, and neuromuscular adaptations. For example, resistance training performed during the follicular phase of the menstrual cycle may elicit greater acute anabolic signaling and muscle protein synthesis, whereas training during the luteal phase may alter substrate utilization, enhance fatigue resistance, and influence recovery dynamics (7-10). Recent studies employing menstrual cycle phase-based interval or sprint training protocols have demonstrated phase-specific differences in muscle protein signaling, neuromuscular adaptations, and endurance performance in trained female athletes, providing evidence for the physiological relevance of cycle-aware training (8,12-14). These findings highlight the importance of incorporating hormonal and menstrual considerations when designing CT programs for women to maximize both performance and adaptive outcomes. High-intensity endurance training, when combined with resistance training, has been shown to induce interference in neuromuscular adaptations, including maximal strength, rapid force production, and muscle hypertrophy, particularly in male athletes (4,5,15). In contrast, women often exhibit less interference, which may be attributed to estrogen-mediated protection against muscle damage, enhanced satellite cell proliferation, improved recovery kinetics, and modulation of inflammatory responses (7,9,10,16,17). Such sex-specific physiological characteristics may explain why the magnitude of the interference effect in women is frequently smaller or more inconsistent than in men. Understanding these underlying mechanisms is essential for optimizing CT program design, particularly regarding the sequencing of resistance and endurance exercises, selection of intensity and volume, and management of recovery periods (11-13,18,19). Research shows that exercise order can significantly influence neuromuscular outcomes during CT. Specifically, performing resistance training before endurance sessions has been associated with greater gains in lower-body strength, whereas reversing the order does not consistently impair endurance or strength outcomes (11,12,20,18-22). Additionally, high-intensity interval-type endurance training, compared to traditional moderate-intensity continuous exercise, may mitigate potential interference effects, further emphasizing the need to tailor CT variables according to the athlete's sex, hormonal status, and performance goals (7,12,15). Moreover, individual responses to CT may vary according to training status, with untrained or recreationally active women showing different adaptation profiles compared to elite or high-level athletes (2,5,23,24). Beyond performance improvements, CT offers a range of health benefits for women, including favorable modifications of cardiometabolic risk factors, improved body composition, enhanced blood pressure regulation, and positive changes in serum lipid profiles (13,25-28). These adaptations are particularly relevant in populations at risk for metabolic syndrome, obesity, or cardiovascular disease, where combined resistance and endurance training may provide superior benefits compared to single-modality interventions (8,20,23,26). Nevertheless, women with high-level athletic performance remain underrepresented in CT research, and interactions among exercise modality, intensity, volume, hormonal status, and potential interference effects are not fully elucidated (2,5,7,23,24). Addressing these gaps is critical for developing evidence-based CT prescriptions tailored to female athletes and non-athletic populations alike. Additional factors influencing CT adaptations in women include recovery strategies, sleep quality, nutritional intake, and the precise manipulation of training variables (29-31). Adequate protein consumption, particularly around training sessions, has been shown to support muscle hypertrophy and maintain lean body mass during energy-restricted periods, further enhancing CT benefits (31). Similarly, appropriate management of recovery, including sleep and periodization strategies, may optimize neuromuscular adaptations and attenuate potential interference effects (29,30,32). Collectively, these findings emphasize the multifactorial nature of CT adaptations in women, wherein biological sex, hormonal milieu, training program variables, and lifestyle factors converge to determine performance and health outcomes. Recent studies have expanded the investigation of CT into specific female populations, including breast cancer survivors and women with metabolic syndrome, demonstrating improvements in physical function, cardiometabolic health, and body composition (18,27,28,33-35). These studies also highlight that concurrent interventions may be more effective than single-mode training in promoting both functional and metabolic adaptations, suggesting that CT can be strategically applied beyond athletic populations (8,14,18,27,28,33-35). Moreover, molecular-level investigations have begun to elucidate how menstrual cycle phase and hormonal contraceptive use influence CT responses, revealing distinct patterns of mTORC1 signaling, insulin sensitivity, and proteomic adaptations during cycle-based training (7,14,16,17). Such mechanistic insights provide a scientific rationale for incorporating female-specific considerations in CT program design. In summary, while concurrent training represents a potent strategy to improve strength, endurance, and body composition, significant gaps remain in our understanding of sex-specific adaptations in women. Key questions include: under which conditions interference occurs, how hormonal fluctuations across the menstrual cycle and contraceptive use modulate responses, and which training variables optimize adaptation while minimizing interference (1-3,5-10,12-15,20,21,24). Addressing these questions requires an integrated approach that combines physiological, molecular, and applied perspectives to inform training prescriptions. Therefore, the present review aims to provide a comprehensive analysis of CT studies published between 2020 and 2025, focusing on three primary areas: 1) functional and body composition adaptations, 2) potential interference and sex-specific differences, and 3) the role of hormonal status, training order, and optimization strategies. By synthesizing current evidence, this review seeks to guide coaches, researchers, and female athletes in designing CT programs that maximize performance, enhance health, and consider the nuanced effects of hormonal and sex-specific factors on adaptation.

Methods

This study is a narrative review with a systematic structure, aimed at identifying, analyzing, and synthesizing scientific evidence on concurrent training in women, with a focus on hormonal effects, adaptation interference, and optimization strategies. The review was designed following the general principles of the PRISMA 2020 guidelines. However, a meta-analysis was not feasible due to heterogeneity in study designs and variables. Literature searches were conducted in the following databases: PubMed, Scopus, Web of Science, Science Direct, Google Scholar, Springer Link, Wiley Online Library, Frontiers in Physiology, Frontiers in Sports and Active Living, and MDPI (Sports, Biology, Nutrients, etc.). All articles published from

January 2020 to January 2025 were considered to ensure the inclusion of the most recent scientific evidence regarding women. The last search was conducted on January 12, 2025. Search terms were used individually and in combination with the Boolean operators AND and OR. Examples of keywords included: *concurrent* training, combined training, resistance and endurance training, interference effect, hormonal fluctuations, concurrent exercise, menstrual cycle, female athletes, women, estrogen, progesterone, mTOR signaling, AMPK, recovery, adaptation, optimization strategies. Example combinations included concurrent training AND women, menstrual cycle AND resistance training, interference effect AND female athletes, hormonal regulation AND endurance training, AMPK AND mTOR AND concurrent exercise, female physiology AND training adaptations. A total of 352 records were identified across databases. After removing duplicates, 282 records remained. Titles and abstracts of these 282 articles were screened, and 90 were excluded because they lacked clear relevance. Full texts of the remaining 192 articles were assessed for eligibility. Of these, 137 were excluded for the following reasons: inappropriate population (Male-only studies or without female-specific analysis), absence of concurrent training intervention, publication before 2020, non-research nature, or lack of access to the full-text. In particular, 12 articles were excluded because their full texts were unavailable through institutional subscriptions, and attempts to obtain them via author contact or interlibrary loan were unsuccessful. Ultimately, 55 studies met the inclusion criteria and were included in the narrative synthesis (Figure 1). Additionally, information about these 55 articles is listed in Table 1. The inclusion criteria were: studies published between January 2020 and January 2025; female participants aged 18-70 years (Athletes or inactive) or mixed-gender studies that reported female outcomes separately; concurrent training interventions (Structured combination of resistance and endurance training within a training period) or studies that directly investigated interference in resistance-endurance training in women; study designs including randomized controlled trials (RCTs), non-randomized controlled trials, interventional studies, relevant observational studies, systematic reviews, and meta-analyses on concurrent training in women. Reported outcomes included at least one of the following: strength and muscle hypertrophy, endurance and maximal oxygen uptake (VO_2max), body composition and metabolic indicators, hormonal variables and menstrual cycle phase, molecular markers, adaptation interference indicators, and training optimization strategies. Exclusion criteria were: male-only or animal studies, mixed-gender studies without separate reporting of female outcomes, publications prior to 2020, non-research articles (Editorials, letters, opinions, protocols, expert commentary, conference abstracts without full data), studies not assessing concurrent training interventions or outcomes related to interference and hormonal interactions, and studies with very low methodological quality based on initial assessments using RoB 2, ROBINS-I, NOS, or AMSTAR 2 (High risk of bias in multiple key domains). Data were extracted independently by two researchers. Extracted information included study population (Age, training status, menstrual cycle status), intervention type (Resistance, endurance, concurrent), training intensity, volume, and sequence, menstrual cycle phase or hormone levels, outcomes (Strength, hypertrophy, endurance, recovery, molecular markers), factors related to adaptation interference, and proposed strategies. Discrepancies between researchers were resolved through discussion or consultation with a third researcher. This rigorous process ensured the completeness and accuracy of data included in tables and subsequent analyses. The quality of the included studies was assessed using validated, study-specific tools. For RCTs, the RoB 2 tool was applied, covering five domains: randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Non-randomized interventional studies were evaluated using ROBINS-I, covering seven domains of bias. Observational studies (Cross-sectional, cohort, or case-control) were assessed using the Newcastle-Ottawa Scale (NOS) across three domains: selection, comparability, and outcome/exposure assessment. Systematic reviews and meta-analyses were assessed using AMSTAR 2. Two independent reviewers scored all studies, and disagreements were resolved through consultation with a third reviewer. Assessment results were presented in a table. Overall, most RCTs were rated as low risk of bias in randomization and outcome measurement domains, although some had "some concerns" regarding selective reporting. Most observational studies scored between 6 and 8 out of 9 on NOS, indicating moderate to high quality. Non-randomized interventional studies were mainly rated "low" to "moderate" risk of bias using ROBINS-I. Systematic reviews were deemed acceptable according to AMSTAR 2. The certainty of evidence was assessed using the GRADE framework, which is appropriate for narrative synthesis without meta-analysis. In GRADE, RCTs start as high-certainty evidence and observational studies as low-certainty, then adjusted based on five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Given that most included RCTs had low to moderate risk of bias, but significant heterogeneity existed in populations (Training status, age), interventions (Order, intensity, endurance type: high-intensity interval vs. continuous), and outcome measurement methods, the overall certainty was rated as moderate for lower-body strength and VO_2max outcomes, low-to-moderate for hormonal and molecular outcomes, and low for long-term interference effects and menstrual cycle-based periodization. Therefore, recommendations from this review should be considered sex-specific but viewed as provisional, pending confirmation through high-quality RCTs with standardized reporting of hormonal status. Reporting quality was assessed using EQUATOR-based checklists depending on study design. RCTs were assessed using the 25-item CONSORT checklist, covering study design, randomization, blinding, participant flow, and data analysis. Observational studies were evaluated using the 22-item STROBE checklist, covering title, abstract, background, methods, results, and interpretation. Systematic reviews and meta-analyses were evaluated according to PRISMA 2020. Overall, reporting quality was satisfactory: most RCTs fully reported key CONSORT items including intervention details and participant flow, while most observational studies addressed at least 18 of 22 STROBE items. Minor omissions mostly involved potential bias and handling of missing data. Among the 55 final studies, variables such as study population, training type, intensity, volume, concurrent training type, hormonal status, and outcomes were examined. Populations included healthy young women, recreationally active women, and athletes. Training types included resistance, endurance, or a combination. Exercise intensity was generally high, with moderate volume of 3-5 sessions per week over 4-12 weeks. Concurrent training protocols included resistance-before-endurance or vice versa, as well as various sequencing models. Hormonal status included estradiol, estrogen, and progesterone, while outcomes evaluated included strength and endurance adaptations, performance, body composition, and training load management. Proposed strategies for optimizing training programs were also presented. Most studies indicated that training order and inter-session interval length could reduce interference effects and optimize hormonal responses. For the purpose of analysis, studies were categorized into three main groups: 1) studies on physiology and hormones (18 articles) examining estrogen and progesterone effects on training responses and the influence of menstrual cycle phase on AMPK-mTOR signaling, recovery, and substrate utilization; 2) studies on concurrent training and interference (24 articles) comparing strength, endurance, and hypertrophy outcomes in concurrent versus single-mode training, assessing training sequence (Resistance before endurance and vice versa), and identifying conditions that mitigate interference; 3) studies on optimization strategies (13 articles) addressing session spacing and intensity, menstrual cycle-based periodization, training volume management, and prioritization of strength or endurance goals. Due to substantial heterogeneity in study design, hormonal assessment methods, participant training status, and outcome measures, a meta-analysis was not conducted. Therefore, a structured narrative synthesis was conducted. Findings were organized into three predefined domains aligned with the objectives of this review: Hormonal responses to concurrent training, Mechanisms underlying interference effects, Optimization strategies in women, within each domain, results were compared, contrasted, and synthesized to identify consistent patterns, discrepancies, and research gaps.

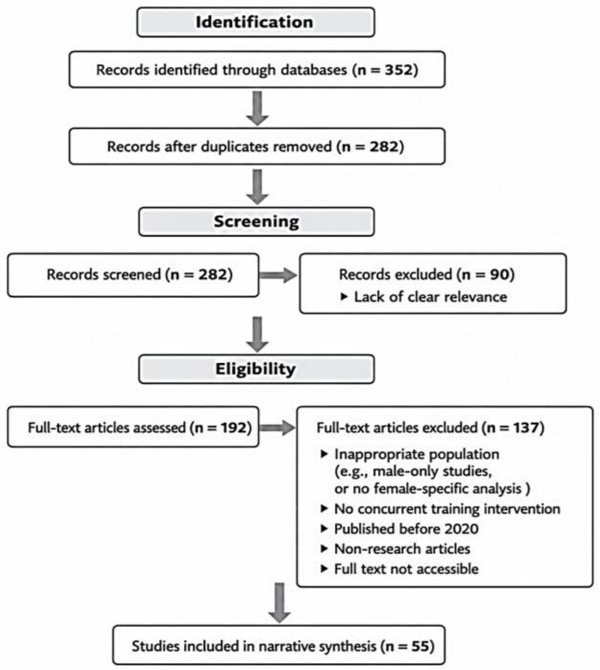

Figure 1. Flow diagram of study identification, screening, eligibility, and inclusion

Results

Published studies from 2020 to 2025 consistently demonstrate that concurrent training, defined as the integration of resistance and endurance exercises within a single program, leads to significant improvements in muscular strength, aerobic capacity, and body composition in women. High-certainty evidence indicates that lower-body strength and muscle hypertrophy are significantly enhanced following ≥8 weeks of concurrent training in healthy adult women (1,2,15), while interference effects commonly observed in men are attenuated in women, particularly for lower-body strength, with upper-body strength and power generally preserved (2,5,36). Exercise sequence markedly influences strength adaptations; performing resistance exercises before endurance training maximizes lower-body strength gains, whereas the reverse order may attenuate these effects (6,12,18,19). Intervention studies in recreational and professional populations further suggest that careful management of exercise order, intensity, and recovery are essential to optimize neuromuscular adaptations and minimize fatigue (18,24,35,37). Moderate-certainty evidence supports the effectiveness of concurrent training in older, inactive women, with significant gains in strength and endurance observed without loss of muscle mass (38).

Regarding aerobic performance, high-certainty evidence demonstrates that concurrent training consistently enhances VO_2max and endurance across diverse female populations, including recreational exercisers and overweight individuals (1,2,7,8,39,40). Incorporating high-intensity interval training (HIIT) with resistance exercise elicits simultaneous improvements in strength and aerobic capacity, even in women with obesity or those at elevated metabolic risk (4,8,27,28). Exercise sequence and alignment with menstrual cycle phases can further optimize VO_2max responses (6,12,22,25). In elite endurance athletes, high-intensity and high-volume concurrent protocols require precise monitoring to prevent chronic fatigue and performance decline, supported by moderate-certainty evidence emphasizing individualized program design (24). Collectively, these findings indicate that concurrent training enhances aerobic performance while minimizing interference when intensity, sequencing, and recovery are carefully controlled. Concurrent training also elicits favorable changes in body composition and cardiometabolic health. High-certainty evidence demonstrates reductions in body fat, improved muscle-to-fat ratio, and positive changes in metabolic markers in women across age groups and fitness levels (1,3,4,7,8,10,23,26-28,39,40). Moderate-certainty evidence further supports the superior efficacy of combined resistance and HIIT protocols over single-mode training in improving these indices (8,27,28). Hormonal fluctuations throughout the menstrual cycle and the use of hormonal contraceptives modulate strength, endurance, and recovery responses. Moderate-certainty studies report that women experience different levels of fatigue and exercise capacity depending on cycle phase, with AMPK-mTOR and other molecular pathways mediating phase-specific adaptations (4-7,9,13,14,16,17,41-43). These mechanistic insights help explain the reduced interference effect in women and underscore the need for individualized program design based on hormonal status. Proper management of nutrition, recovery, and training load further mitigates interference and optimizes concurrent training outcomes (3,8,29-32,36). Overall, the current evidence indicates that concurrent training effectively improves muscular strength, aerobic capacity, and body composition in women. High-certainty evidence supports gains in lower-body strength, VO_2max, and reductions in body fat, while moderate-certainty evidence highlights the importance of exercise sequence, intensity control, recovery strategies, and hormonal considerations. These findings provide clear guidance for designing sex-specific concurrent training programs and highlight the practical importance of individualized programming to maximize functional and health-related adaptations in women.

Table 1. Studies reviewed in the present study

Number	Author / Year	Country	Sample Size	Age	Type of Study	Duration	Outcomes / Conclusions
1	Mikkonen RS, Ihalainen JK, Hackney AC, Häkkinen K. 2024	Finland	Systematic Review (No primary sample)	Adults	Systematic Review	N/A	Outcomes: Neuromuscular, hormonal, and hypertrophic and endurance responses; Conclusion: Interference depends on intensity, sequencing, and individual factors.
2	Huiberts RO, Wüst RCI, van der Zwaard S. 2024	Netherlands	Meta-analysis (No primary sample)	Adults	Systematic Review and Meta-Analysis	N/A	Outcomes: Strength and endurance adaptations; Conclusion: Sex and training status modulate interference; women may show less interference.
3	Wang T, Bo S. 2024	China	Narrative Review (No primary sample)	Adults	Narrative Review	N/A	Outcomes: Strength, endurance, recovery factors; Conclusion: Sequence, intensity and volume influence adaptations.
4	Delgado-Floody P et al. 2022	Chile	60 Women (Study reported)	30-55 y	RCT	12 Weeks	Outcomes: Body composition, strength, VO2max; Conclusion: Improved metabolic and performance markers with interindividual variability.
5	Taipale RS et al. 2020	Finland	40 Women, 40 Men (Women subset)	20-35 y	RCT	10 Weeks	Outcomes: Strength, endurance; Conclusion: Women show preserved strength gains; menstrual cycle phase influences adaptations.
6	Ekenros L et al. 2022	Sweden	1,086 Female athletes	16-40 y	Cross-Sectional Survey	N/A	Outcomes: Self-reported performance, fatigue, training; Conclusion: Cycle phase and contraceptive use affect perceived performance and recovery.

Table 1 (Continued)

7	Taipale-Mikkonen RS et al. 2021	Finland	50 Women	18-35 y	Crossover Trial	6 Weeks	Outcomes: Strength, power, endurance; Conclusion: Hormonal fluctuations modify physiological responses to training.
8	Bouamra M et al. 2022	France	72 Obese adolescents (Mixed sex)	14-18 y	RCT	12 Weeks	Outcomes: Body composition, strength, VO2max; Conclusion: Concurrent training superior to single-modality in obese youth.
9	Osmani F et al. 2024	Italy	30 Women	18-30 y	Observational Study	4 Weeks	Outcomes: Strength across menstrual phases; Conclusion: Strength largely maintained with minor fluctuations.
10	Trowell D et al. 2022	United Kingdom	45 Women	20-35 y	RCT	10 Weeks	Outcomes: Running performance and biomechanics; Conclusion: Improved endurance and mechanics without compromising strength.
11	Prieto-González P, Sedlacek J. 2022	Spain	60 Female runners	18-30 y	RCT	12 Weeks	Outcomes: Strength, endurance, running economy; Conclusion: Combined training produced superior gains.
12	Gao J, Yu L. 2023	China	Systematic Review/Meta (No primary sample)	Adults	Systematic Review and Meta-Analysis	N/A	Outcomes: VO2max, lower limb strength; Conclusion: Exercise order affects strength more than endurance.
13	Chen Y et al. 2024	China	Network meta-analysis (No primary sample)	Adults	Network Meta-Analysis	N/A	Outcomes: Lower-body strength, hypertrophy; Conclusion: Sequence and type influence adaptations.
14	Delgado-Floody P et al. 2021	Chile	50 Women	25-50 y	RCT	20 Weeks	Outcomes: Strength, body composition, endurance; Conclusion: RT-first better for hypertrophy; HIIT-first better for endurance.
15	Seipp D et al. 2023	Germany	Systematic Review (Various)	Female athletes	Systematic Review	N/A	Outcomes: Performance, strength, endurance; Conclusion: Feasible in team sports with minimal interference.
16	Kubica C et al. 2024	Poland	40 Women	18-30 y	RCT	12 Weeks	Outcomes: VO2max, CV markers; Conclusion: Cycle-based polarized training optimizes endurance adaptations.
17	Kissow et al., 2024	Denmark	n = 30 Female athletes	Young adult women (Exact age not reported)	Randomized Controlled Intervention Study (Preprint)	12 Weeks	Outcomes: Menstrual cycle phase-based interval training induced distinct muscular adaptations compared with conventional training. Training concentrated during specific menstrual phases may enhance muscle hypertrophy and performance adaptations in female athletes.
18	Pareja-Blanco et al., 2017	Spain	n = 43 Trained	23 ± 3 years	Randomized Controlled Trial	8 Weeks	Outcomes: Lower velocity loss during resistance training resulted in superior neuromuscular performance, greater power gains, and less fatigue accumulation than higher velocity-loss protocols.
19	O'Bryan SM et al. 2022	USA	N/A (Methodological review)	Adults	Narrative Review	N/A	Outcomes: Methodology/reporting; Conclusion: Report cycle phase/HC use critical in research.
20	Vikestad V, Dalen T. 2024	Norway	30 Women	18-30 y	RCT	12 Weeks	Outcomes: Endurance performance; Conclusion: Sequence modifies endurance outcomes; RT-first favored.
21	Markov et al., 2025	Germany	n = 24 Female youth judo athletes	Adolescents	Randomized Crossover Trial	Acute intervention	Outcomes: Exercise order during concurrent training affected acute immunological stress responses and muscular fitness outcomes. Strength-before-endurance produced more favorable neuromuscular responses.
22	Monteiro et al., 2015	Brazil	n = 30 Obese adolescents	15-19 years	Randomized Controlled Trial	20 Weeks typical	Outcomes: Concurrent training and aerobic training produced similar improvements in body composition, metabolic profile, and obesity-related health markers.
23	Álvarez et al., 2019	Spain	n = 606 Adults	Middle-aged adults	Intervention Study	16 Weeks	Outcomes: Concurrent training effectively reduced hyperglycemia and cardiometabolic risk factors, although individual variability resulted in some non-responders.
24	Kissow J et al. 2025	Denmark	20 Women	18-30 y	Intervention / Proteomics	6 Weeks	Outcomes: Molecular signaling, muscle adaptation; Conclusion: Proteomic adaptations differ by menstrual phase.
25	Ho et al., 2012	Australia	n = 97 Overweight and Obese adults	18-65 years	Randomized Controlled Trial	12 Weeks	Outcomes: Aerobic, resistance, and concurrent exercise all improved cardiovascular risk factors. Combined training produced broad health benefits.
26	Denadai and Greco, 2025	Brazil	N/A (Narrative/Hypothesis)	Adults	Hypothesis paper	N/A	Outcomes: Proposed an alternative model explaining the interference phenomenon, emphasizing the role of muscle fatigue and recovery processes.

Table 1 (Continued)

27	Wadsworth et al., 2022	USA	n = 38 Inactive older women	60-75 years	Intervention study	16 Weeks	Outcomes: Concurrent training significantly improved strength, functional capacity, and aerobic fitness in inactive aging women.
28	Liu C et al. 2025	China	28 Elite triathletes	20-30 y	Intervention (Elite)	10 Weeks	Outcomes: Endurance, strength; Conclusion: Feasible for elite females with periodization.
29	Bernedo et al., 2024	Australia	n = 14 Participants	Young adults	Experimental study	Acute intervention	Outcomes: Performing high-intensity strength training before HIIT did not produce substantial interference effects on acute performance responses.
30	Madeira et al., 2024	Portugal	28 Studies included	Breast cancer survivors	Systematic Review and Meta-Analysis	Variable across studies	Outcomes: Concurrent training improved physical fitness, quality of life, fatigue, and several biomarkers in breast cancer survivors.
31	Gerland et al., 2021	Germany	Multiple studies	Breast cancer patients	Narrative Review	N/A	Outcomes: Resistance exercise is safe and effective for breast cancer patients and improves strength, physical function, and quality of life.
32	Jones et al., 2013	United Kingdom	n=18	21 ± 3 years	Randomized Controlled Trial	12 Weeks	Outcomes: Different strength-to-endurance training ratios influenced neuromuscular and endurance adaptations. Training emphasis affected performance outcomes.
33	Petré et al., 2021	Sweden	43 Studies included	Various populations	Systematic Review and Meta-Analysis	6-12 Weeks	Outcomes: Concurrent training can effectively improve maximal strength, although training status influences adaptation magnitude.
34	Yu et al., 2025	South Korea	n = 48 Obese women with prehypertension	Adult women	Randomized Controlled Trial	6 Weeks	Outcomes: Concurrent training improved blood pressure, body composition, metabolic health, and physical fitness regardless of aerobic modality.
35	Hagstrom et al., 2020	Australia	24 Studies included	Adult women	Systematic Review and Meta-Analysis	6-20 weeks	Outcomes: Resistance training significantly increased dynamic strength and muscle hypertrophy in women.
36	Lesinski et al., 2016	Germany	43 Studies included	Youth athletes	Systematic Review and Meta-Analysis	Variable across studies	Outcomes: Resistance training produced significant improvements in strength, power, speed, and athletic performance in youth athletes.
37	Ekenros et al., 2024	Sweden	n = 1,000+ female athletes	Adult athletes	Cross-Sectional Survey	N/A	Outcomes: Many female athletes perceived menstrual cycle phases and hormonal contraceptives as influencing training quality and performance.
38	Liu et al., 2026	China	24 studies included	Postmenopausal women	Meta-Analysis	Variable across studies	Outcomes: Concurrent training significantly improved body composition, reduced body fat percentage, enhanced metabolic health markers, and decreased inflammatory indicators in postmenopausal women. The findings support concurrent training as an effective non-pharmacological strategy for improving health outcomes after menopause.
39	Sims and Heather, 2023	New Zealand	Not applicable	Not applicable	Methodological Review	N/A	Outcomes: The authors highlighted major methodological limitations in studies investigating sex differences and menstrual cycle effects. They emphasized the need for rigorous menstrual cycle verification, standardized research designs, and improved reporting practices to reduce bias and improve reproducibility in female exercise physiology research.
40	Lloyd et al., 2021	United Kingdom	N/A (Syntheses/Perspectives)	Children and adolescents	Narrative Review / Position-Oriented Review	N/A	Outcomes: Agility development should be systematically integrated throughout childhood and adolescence using age-appropriate neuromuscular, strength, speed, and motor skill training. Long-term athletic development programs can substantially enhance agility performance and reduce injury risk in youth athletes.
41	McMahon GE et al. 2022	United Kingdom	Experimental sample (See paper)	Adults (Women athletes)	Intervention/Experimental	N/A	Outcomes: Power development; Conclusion: ROM affects power adaptation.
42	Belamjahad et al., 2024	France	n = 31 female soccer players	Young female athletes	Controlled Intervention Study	Preseason period (8 weeks)	Outcomes: Neuromuscular training was more effective than endurance-dominated training for improving physical fitness and reducing injury risk in female soccer players.

Table 1 (Continued)

43	Petersen and Fyfe, 2021	Australia	N/A (Review)	Adults	Narrative review	N/A	Outcomes: Cold-water immersion after resistance training may attenuate hypertrophy-related signaling pathways and potentially reduce long-term muscle adaptations.
44	Marquet et al., 2016	France	n = 21 endurance-trained athletes	Adult athletes	Randomized Crossover Study	3 Weeks	Outcomes: The "Sleep Low" carbohydrate-periodization strategy significantly improved endurance performance compared with conventional nutrition approaches.
45	Grgic J et al. 2022	Various	N/A (Meta-analysis)	Adults	Systematic review and meta-analysis	6-20 weeks across included trials	Outcomes: Strength, hypertrophy; Conclusion: Training to failure not always necessary.
46	Lopez P et al. 2021	Various	N/A (Network meta-analysis)	Adults	Systematic Review and Network Meta-Analysis	Varied	Outcomes: Load effects on hypertrophy; Conclusion: Load influences hypertrophy and strength.
47	Wen et al., 2019	International	36 RCTs included	Adults	Meta-Analysis	Variable across studies	Outcomes: HIIT significantly improved VO_2max, with training volume and intensity influencing the magnitude of improvement.
48	Atakan MM et al. 2021	Various	N/A (Review)	Adults	Narrative Review	N/A	Outcomes: HIIT effects on exercise capacity; Conclusion: Evidence supports HIIT efficacy.
49	von Rosen P et al. 2022	Sweden	1,086 female athletes	Varied	Cross-Sectional Survey	N/A	Outcomes: Support/knowledge about menstrual cycle; Conclusion: Gaps in resources; need education.
50	Hawley, 2009	Australia	Experimental sample	Adults (Women)	Narrative Review	N/A	Outcomes: Discussed molecular signaling pathways underlying endurance and resistance training adaptations. Concluded that AMPK and mTOR interactions may partially explain the concurrent training interference phenomenon.
51	Nelson et al., 2025	USA	n = 30 Women	Reproductive-age women	Experimental Observational Study	One menstrual cycle	Outcomes: Menstrual cycle phase influenced skeletal muscle mitochondrial respiration. Mitochondrial function exhibited phase-dependent variations, suggesting hormonal modulation of muscle bioenergetics.
52	Taylor et al., 2024	Norway	n = 16 Endurance-trained women	Adults (Women)	Repeated-Measures Observational Study	One menstrual cycle	Outcomes: Menstrual cycle phase influenced sleep quality and recovery responses following exercise, with recovery markers varying across phases.
53	Heileson et al., 2022	USA	n = 120 Army personnel	Adults	Cross-Sectional Study	Varied	Outcomes: Body composition, vitamin D status, and eicosapentaenoic acid levels were significantly associated with military fitness performance.
54	Schumann et al., 2022	International	66 Studies included	Various populations	Systematic Review and Meta-Analysis	Variable across studies	Outcomes: Concurrent training is largely compatible with gains in muscle size and function, although endurance training volume can influence outcomes.
55	Vikmoen, 2019	Norway	N/A (Perspective)	Adults	Book Chapter	N/A	Outcomes: Reviewed sex differences in concurrent training adaptations and highlighted the limited female-specific evidence base.

Discussion

This review synthesizes current evidence regarding concurrent training adaptations in women, focusing on hormonal responses, interference mechanisms, and optimization strategies. Overall, findings suggest that the female hormonal milieu may partially modulate concurrent training outcomes. Moderate-certainty evidence indicates a potential protective role of estrogen in attenuating muscle damage and preserving strength adaptations (1,2), whereas evidence regarding recovery during the luteal phase remains limited and inconsistent (6,7). Previous reviews on concurrent training have largely relied on male-dominant samples and have consistently reported the potential for interference effects, particularly when endurance exercise precedes resistance training (1,2,44,45). However, few earlier syntheses have specifically examined female populations (1,2,46,47). The present findings extend prior literature by suggesting that hormonal fluctuations unique to women may influence interference magnitude (6,7,13,16). While earlier models emphasized AMPK-mediated inhibition of mTOR signaling as a primary explanation for reduced hypertrophy (1,2,17), our synthesis indicates that such mechanisms may not fully translate to female physiology. This aligns with emerging research suggesting sex-based differences in anabolic sensitivity and muscle damage responses (1,2,16,17). Estrogen's membrane-stabilizing and antioxidant properties may reduce muscle damage following concurrent training stimuli (1-3,16). Additionally, potential modulation of satellite cell activation and anabolic signaling pathways may attenuate classical interference mechanisms (1,2,17). However, direct molecular evidence in women remains scarce; therefore, mechanistic conclusions should be interpreted cautiously (1,2,16). Progesterone-related influences on thermoregulation and substrate metabolism may explain inconsistencies observed during the luteal phase (6,7,25). Elevated core temperature and altered glycogen utilization could modify fatigue and recovery kinetics, potentially affecting adaptation outcomes (1-3). Considerable heterogeneity was observed across studies. Differences in training status, caloric intake control, menstrual phase verification methods, and exercise sequencing protocols likely contributed to inconsistent findings (4,5,12,18,35). Importantly, many studies did not biochemically confirm menstrual phase, relying instead on calendar-based tracking, which may reduce internal validity (6,7,42). Furthermore, small sample sizes and short intervention durations limit confidence in long-term adaptation conclusions (5,24,38). Although definitive prescriptions cannot be established, evidence tentatively supports the following considerations: Resistance-first sequencing may attenuate interference magnitude (18,19,35) .Aligning high-intensity resistance sessions with the follicular phase may enhance anabolic responses (13,16,17).Individual variability and nutritional adequacy should be considered in program design (29-31). However, given the low to moderate certainty of evidence, practitioners should apply these strategies cautiously (47-52). Finally, practical strategies and optimization indicate that precise programming, control of intensity and volume, proper nutrition, and adequate recovery intervals can reduce interference effects (3,8,29-32,36). Recommendations include attention to exercise sequence, type of endurance exercise, menstrual cycle phase, and the needs of specific populations (1). Recent evidence suggests that resistance and concurrent training variables can substantially influence neuromuscular adaptations, power development, and athletic performance outcomes, particularly in female populations. Training strategies that emphasize agility development and neuromuscular coordination appear essential for optimizing explosive performance across different stages of physical development (51). Furthermore, manipulation of range of motion during explosive resistance training has been shown to significantly affect power-related adaptations in women, indicating that exercise execution characteristics may play an important role in maximizing performance outcomes (52). In female soccer players, concurrent power and endurance training has also demonstrated positive effects on explosive actions, supporting the effectiveness of integrated training approaches for enhancing sport-specific performance (53). In addition, resistance training programming variables such as proximity to muscular failure and training load appear to influence strength and hypertrophic adaptations. Although training to failure may not always provide superior benefits compared with non-failure approaches, both methods can effectively improve muscular strength and hypertrophy when appropriately programmed (54). Similarly, a wide spectrum of resistance training loads has been shown to promote muscular adaptations, suggesting that both moderate and heavy loads can be effective depending on training goals and individual characteristics (55). Overall, three key findings emerge from current evidence: first, well-designed concurrent training can effectively improve strength, endurance, and body composition in women; second, individual hormonal fluctuations and menstrual cycle phases critically influence training adaptations and should guide program design; and third, further rigorous, long-term studies with molecular measurements are needed to clarify mechanisms and confirm sustained benefits.

Conclusion

Concurrent training in women, when properly designed, can lead to significant improvements in strength, endurance, and body composition. The present review indicates that the interference effect appears to be less pronounced in women than in men, although it still exists and should be considered when designing programs. Hormonal fluctuations and individual differences play a major role in training responses, and taking the menstrual cycle into account can help optimize outcomes. Evidence suggests that performing resistance training before endurance exercise, providing sufficient time between sessions, periodizing training according to the menstrual cycle, and appropriately managing training volume and intensity are the most effective strategies to mitigate interference. However, many existing studies are limited by small sample sizes, protocol heterogeneity, lack of menstrual phase control, and limited molecular assessments. Based on the reviewed evidence, concurrent training can be a safe and effective approach for women, if scientific training design principles are followed. The findings of this study may provide practical guidance for coaches, researchers, and female athletes to design effective, individualized training programs aligned with hormonal patterns.

Given the findings of this review and current literature limitations, further rigorous and comprehensive studies are warranted. A key research need is long-term follow-up studies to examine the sustained effects of concurrent training on strength, endurance, body composition, and musculoskeletal and cardiovascular health in women over periods exceeding 12 weeks. Additionally, studies should implement stricter control over menstrual cycle and hormonal fluctuations, as different phases can affect training responses and related molecular pathways such as AMPK–mTOR. Future research should also investigate cellular and biomolecular markers, as well as anabolic and catabolic signaling pathways, to elucidate the precise mechanisms of concurrent training adaptations in women. Moreover, there is a need for individualized training program designs for women with different fitness levels and goals, determining the optimal exercise sequence, session spacing, and intensity and volume according to hormonal and physiological characteristics. Most existing studies have focused on young, healthy, or active women, while broader populations, including middle-aged, postpartum, overweight, and menopausal women are understudied. Expanding research to these groups would provide a more comprehensive understanding of concurrent training effects across a wider female population. Finally, the development of interdisciplinary studies integrating exercise physiology, nutrition, neuroscience, and mental health could offer a more holistic perspective on the effects of concurrent training. Investigating psychological, cognitive, and neurological outcomes of this training approach may inform the design of more comprehensive and effective programs for women.

Abbreviations

mTOR: Mechanistic Target of Rapamycin; mTORC1: Mechanistic Target of Rapamycin Complex 1; AMPK: AMP-activated protein Kinase; AMPK-mTOR: AMP-Activated Protein Kinase-Mechanistic Target of Rapamycin; HIIT: High Intensity Interval Training; CT: Concurrent Training; RCTs: Randomized Controlled Trials; NOS: Newcastle-Ottawa Scale; ROBINS-I: Risk Of Bias In Non-randomized Studies of Interventions; AMSTAR: A MeaSurement Tool to Assess Systematic Reviews; CONSORT: Consolidated Standards of Reporting Trials; STROBE: Strengthening the Reporting of Observational Studies in Epidemiology; EQUATOR: Enhancing the QUAlity and Transparency Of Health Research.

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Ethical statement

This study is a review article and did not involve any new experiments on human or animal subjects.

Conflicts of interest

This research was conducted independently, and no conflict of interest is reported.

Author contributions

ESH and MGH: Conceptualization, Data analysis and Interpretation, Summarization of results, Initial manuscript drafting. ESH and MGH and MGH: Conceptualization, Data interpretation, Content review, and Manuscript revision. All authors have read and approved the final version of the manuscript.

Data availability statement

This article is a systematic review, and extracted data from the included studies are accessible through reputable databases.

Use of artificial intelligence

No generative AI tools were used in the writing, analysis, or preparation of this manuscript.

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