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Hormonal changes in strength training during the menstrual cycle: a systematic review

Alterações hormonais no treinamento de força durante o ciclo menstrual: revisão sistemática

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ABSTRACT

Introduction: During the menstrual cycle, women are exposed to continual variations in serum concentrations of various female sex steroid hormones. The fluctuations of the main female hormones (estrogen, progesterone, follicle stimulating hormone and luteinizing hormone) are essential for regulating ovulatory cycle patterns. In this sense, it is speculated that strength training can stimulate the signaling pathways of essential hormones to regulate the patterns in the different phases of the ovulatory cycle. **Objective:** To analyze hormonal changes and strength performance in different phases of the menstrual cycle in women experienced in strength training. **Methods:** A systematic review was carried out following the PRISMA recommendations. The terms "Strength Training", "Resistance Exercise" and "Menstrual Cycle" were searched in Medline (PubMed), Virtual Health Library (VHL). and ScienceDirect databases. We included experimental studies that evaluated hormonal changes during the menstrual cycle in strength training in women trained in resistance exercise. **Results:** From a total of 592 documents, six studies met the inclusion criteria. Interventions in the included studies ranged from 2 to 140 days. The protocols demonstrated that the intervention with strength training changes progesterone, testosterone, estradiol, and ammonia in the follicular and luteal phases. **Conclusion:** The studies investigated in this review demonstrated that strength training induced hormonal and strength increases, in the follicular phase of the menstrual cycle, in women experienced in strength training.

Keywords: strength training; resistance exercises; menstrual cycle.

RESUMO

Introdução: Durante o ciclo menstrual, as mulheres são expostas a variações contínuas nas concentrações séricas de diversos hormônios esteroides sexuais femininos. As flutuações dos principais hormônios femininos (estrogênio, progesterona, hormônio folículo estimulante e hormônio luteinizante) são essenciais para regular os padrões do ciclo ovulatório. Neste sentido, especula-se que o treinamento de força pode estimular as vias de sinalização dos hormônios essenciais para regular os padrões nas diferentes fases do ciclo ovulatório. **Objetivo:** Analisar as alterações hormonais e o desempenho da força nas diferentes fases no ciclo menstrual em mulheres experientes submetidas ao treinamento de força. **Métodos:** Foi realizada uma revisão sistemática seguindo as recomendações do PRISMA. Foram pesquisados, nas bases de dados Medline (PubMed), Biblioteca Virtual em Saúde (BVS) e ScienceDirect, os termos "Strength Training", "Resistance Exercise" e "Menstrual Cycle". Foram incluídos estudos experimentais que avaliaram as alterações hormonais durante o ciclo menstrual no treinamento de força em mulheres treinadas no exercício resistido. **Resultados:** De um total de 592 documentos, seis estudos preencheram os critérios de inclusão. As intervenções dos estudos incluídos variaram de 2 a 140 dias. Os protocolos demonstraram que a intervenção com o treinamento de força proporcionou alteração nos hormônios progesterona, testosterona, estradiol e amônia nas fases folicular e lútea. **Conclusão:** Os estudos investigados nesta revisão demostraram que o treinamento de foça induziu aumentos hormonais e da força, na fase folicular do ciclo menstrual, em mulheres experientes em treinamento de força.

Palavras-chave: treinamento de força; exercícios de resistência; ciclo menstrual.

Introduction

The menstrual cycle is a complex process involving cell replication and growth under the influence of hormones, growth factors, neurotransmitters, and regulatory molecules [1]. It is repeated at regular intervals of 21 to 36 days, with an average of 28 days and consists of a phenomenon essentially linked to the reproductive life of women [2].

The physiology of the menstrual cycle depends on the balance between the pituitary-ovaries hypothalamus axis. Thus, the menstrual cycle requires the secretion of gonadotropin-releasing hormone (GnRH) by the hypothalamus in a critical range of amplitude and frequency [3]. During menstrual cycle, estrogen and progesterone are responsible for changes that occur in the endometrium, uterine cervix, and vagina, in addition to feedback regulation of secretion of the follicle stimulating hormone (FSH) and luteinizing hormone (LH) by the anterior pituitary [4].

The MC is composed of four phases. The follicular phase of the menstrual cycle lasts from 10 to 20 days and ends with ovulation; the luteal phase lasts for 14 days; and menstrual, from four to seven days [5]. During this period, ovarian hormones (estrogen and progesterone) undergo changes in their concentrations, thus demarcating the phases of menstrual cycle [1]. These phases are known as follicular phase and luteal phase, which are separated by ovulatory period [6].

The follicular phase begins on the first day of the menstrual cycle and ends at the end of the ovulatory period, being characterized by a gradual increase in follicle stimulating hormone (FSH), low progesterone levels and an estrogen peak near the ovulatory phase [1]. The luteal phase begins at the end of the ovulatory phase and lasts until the next menstrual flow, presenting an increase in the concentration of both estrogen and progesterone [7].

During the menstrual cycle, the hormones estrogen and progesterone are two primary sex hormones that fluctuate in three distinct hormonal environments: the early follicular phase characterized by low concentrations of estrogen and progesterone, the late follicular phase (or peri-ovulatory) characterized by high concentrations of estrogen and low progesterone, and the luteal phase, in which high levels of estrogen and progesterone are present [8].

Chidi-Ogbolu & Baar [9] demonstrated that women practicing strength training (ST) in menstrual cycle can stimulate the signaling pathways induced by hormones such as estrogens and androgens, which are groups of endogenous sex hormones produced by women and men [10].

Knowles *et al.* [11] reported the increase in estrogen during the late follicular phase in ST performance, as there is increased strength in the follicular phase and declines in the middle phase of luteum. However, estrogen becomes more abundant after an acute ST session, generating an increase of 65-95 minutes in the luteal phase compared to the follicular phase [12]. Then estradiol remains up to 21% higher than resting levels within 24 hours after training [13].

Rechichi *et al.* [8] point out that estrogen has a greater strengthening effect on skeletal muscle, although the basic mechanism is not clearly known. Variations during the menstrual phase may be a consequence of changes because of ST on metabolism, which are again attributed to fluctuations observed in the concentrations of ovarian hormones [14].

The difficulties around the day of the test that coincide with hormonal fluctuations and evaluation hormones to ensure that the correct phase is being examined may be some of the reasons for the development of few investigations on ST and menstrual cycle [15]. Thus, the aim of this systematic review was to analyze hormonal changes and strength performance in different phases of the menstrual cycle in experienced women submitted to ST.

Methods

Table I shows the PICOS strategy used to delimit inclusion criteria. We excluded studies were excluded with sedentary women who used some contraceptive method, who had already gone through menopause or who performed any other type of training.

Eligibility criteria

Table I shows the PICOS strategy used to delimit inclusion criteria. We excluded studies were excluded with sedentary women who used some contraceptive method, who had already gone through menopause or who performed any other type of training

Table I - PICOS strategy

Initials	Description	Analysis
P	Participants	Women practicing strength training during the menstrual cycle
I	Intervention	Strength training
C	Comparation	Pre, during and post strength training
O	Outcomes	Effects of strength training during the menstrual cycle
S	Study design	Experimental

Search strategy

A search without filters was performed in Medline (via PubMed), Virtual Health Library (VHL) and ScienceDirect databases, in October 2022, using the terms "Strength Training", "Resistance Exercise" and "Menstrual Cycle". These descriptors were combined using the logical operators [OR] (between synonyms) and [AND] (between the terms). After the references were extracted using the search terms, they were exported to a shared EndNote X8 library. Two independent evaluators completed the research, the removal of duplicates, the analysis of titles and abstracts and the screening of the complete articles. Any divergences in the analysis were forwarded to

a third evaluator. Then, the studies were read to verify the articles that met the eligibility criteria of the present study.

Bias analysis

The The Risk Of Bias In Non-randomized Studies (ROBINS-I) tool was used to assess the risk of bias in the studies included in this review [17]. The studies were classified as "selection bias", "performance bias", "detection bias", "monitoring bias", "report bias", "bias due to lack of data" and "bias" in the selection of reported results, with the answers "yes", "probably yes", "probably no", and "no". Two independent and experienced evaluators analyzed the risk of bias in the included studies. The disagreements were resolved by a third evaluator.

Data collection process

The following data were extracted from the selected studies: country, number of participants in each group, age, body mass, height, and duration of the menstrual cycle (Table I), intervention protocol, muscles tested, methodologies, tests used and training load for data analysis (Table II and III), and hormone analysis (Tables VI).

Results

In total, 594 studies were found following the proposed research methodology (Medline = 43; VHL = 65; ScienceDirect = 484). After the use of the selection criteria, six articles were included in this review (Figure 1).
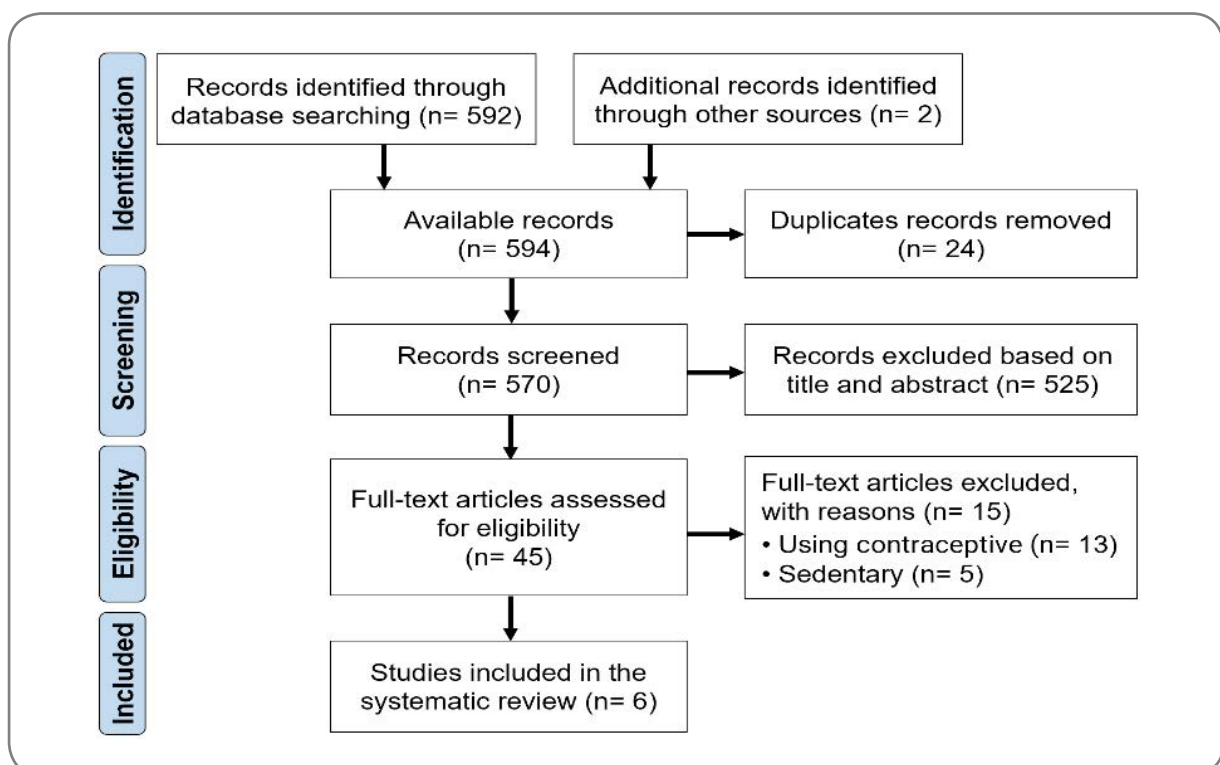

Figure 1 - PRISMA flowchart of the study selection process

Table II presents the characteristics of the studies, study countries and sample characteristics of the studies included in this review. When analyzing the six studies in Table II, we observed a population of 81 trained women (mean age: 26.3 ± 2.39 years; body mass: 62.11 ± 2.14 kg; height: 164.5 ± 3.96 m).

Table II - Descriptive characteristics of the studies included in this review

Study	Country	type	N	Sample characteristics			
				Age (years)	Height (cm)	BM (kg)	DCM
Kraemer *et al.* **[18]**	USA	Exp.	9	24.1±4.3	161.6±7.6	63.4±11.9	30±2.82
Reis *et al.* **[19]**	Germany	-	7	24.4±3.5	171±6.4	65.6±4.6	28.36±0.95
Jonge *et al.* **[20]**	Netherlands	Exp.	19	29.9±8.0	167±7	61.4±8.4	-
Elliott *et al.* **[21]**	UK	Exp.	7	25±5	160±0.1	62.1±2.7	29±1
Sung *et al.* **[22]**	Germany	Exp.	20	25.9±4.5	164.2±5.5	60.6±7.8	28.6±2.3
Parra *et al.* **[23]**	Spain	-	19	28.6±5.9	163.4±6.1	59.6±5.8	24-35 dias

USA = United States of America; UK = United Kingdom; Exp = Experimental; BM = Body Mass; DMC = Duration of the menstrual cycle

Table III shows the methodological characteristics and the results related to the resting conditions in the imposition of the maximum load, in six of the studies, including intervention days, the exercises evaluated, the maximal repetition test, training protocol, interval between sets, and training load.

Table III - Methods and results of the studies included in this review

Study	Inter. days	Exercises used	P-value	Test used	Training protocol	Inter. Bet. series	Training load
Kraemer *et al.* **[18]**	21 days	KE, MS, IA, RB, PD, DT, LP	P<0.05	5-10MR	1×5-10RM	1-3 min	29 ± 4.9
Reis *et al.* **[19]**	15 days	ILP	P=0.026	-	3×12 (uni.) EE	15 min	–
Jonge *et al.* **[20]**	3 days	IHE, IHF	P<0.05	Iso	5x10RM	2 min	60°,240° Iso
Elliott *et al.* **[21]**	2 days	PFB	P<0.05	MVIF	3x Iso	3 min	41.73±20.82
Sung *et al.* **[22]**	140 days	LP e BS	P<0.05	-	3×8-10 80%RM 3×15-20RM	3-5 min	–
Parra *et al.* **[23]**	–	BS	P<0.05	1MR	10x10RM	2 min	75.8 ± 0.26

Inter = intervention; LP = Leg press; BS = back squat; KE = Knee extension; MS = Military Squat; IA = Inclined abdominal; LR = Low rowing; PD = Pulldown; DT = Direct thread; PFB = Pulled from behind; IHF = isokinetic hip flexion; IHE = Isokinetic hip extension; MR = Maximum repetition; MVIF = Maximum voluntary isometric force; ISO = Isometry; Inter = interval; bet = between; ILP = Isometric leg press

Table IV – Result of hormone variation pre, during and post ST during the follicular phase

Study	Hormonal concentration	Pre-training		Post-training	
		FP	LP	FP	LP
Kraemer et al. [18]	S5/3	190.34±130.73	156.19±55.08	265.44±186.73	142.96±110.15
	S10/3	120.06±110.82	166.58±96.10	169.39±87.20	120.20±88.20
	S5/1	167.44±142.76	210.71±101.38	137.75±58.15	193.69±80.20
	H10/1	120.28±101.52	230.56±147.65*	239.48±181.57*	126.92±92.42
	H5/1	107.16±44.85	208.98±89.40*	202.23±107.13*	125.35±125.75
	H10/3	173.77±115.07	184.30±101.62	173.03±132.33	143.34±60.44
Reis et al. [19]	E2 (pmol/l)	150.2 ± 52.0	313.7 ± 165.3	153.4 ± 52.9	337.2 ± 176.0
	P4 (nmol/l)	0.45 ± 0.45	32.96 ± 21.02	0.29 ± 0.16	32.25 ± 21.27
	SHBG (nmol/l)	46.30 ± 21.94	49.66 ± 24.45	52.28 ± 26.60	54.27 ± 27.37
	T(nmol/l)	3.37 ± 0.97	2.92 ± 1.15	3.47 ± 1.63	2.98 ± 0.97
	C(nmol/l)	393.9 ± 181.3	297.0 ± 51.3	331.5 ± 146.6	277.4 ± 162.0
	T(nmol/l)/ SHBG (nmol/l×100)	2.95 ± 2.68	2.35 ± 2.20	2.35 ± 1.73	2.09 ± 1.68
Jonge et al. [20]	Estrogen (pmol l-1)	170.1 ± 116.8	533.5 ± 289.6*	-	369.7 ± 126.9*
	P (nmol l-1)	6.53 ± 12.12	2.45 ± 1.30	-	40.63 ± 19.17*
	FSH (i.u. l-1)	5.18 ± 2.31	7.56 ± 3.85*	-	3.29 ± 3.38*
	LH (i.u. l-1)	6.01 ± 3.87	24.87 ± 21.12*	-	4.76 ± 2.96*
	Estrogen (pmol l-1)	170.1 ± 116.8	533.5 ± 289.6*	-	369.7 ± 126.9*
	Estradiol (pmol l-1)	110.8 ± 61.6	464.7 ± 83.5	-	-
Elliott et al. [21]	P (nmol l-1)	3.3 ± 1.5	36.2 ± 28.3	-	-
	T (nmol l-1)	0.7 ± 0.2	0.8 ±0.1	-	-
	E2 (pg/ml)	124 ± 104	114 ± 71	92 ± 70	142 ± 41*
Sung et al. [22]	P4 (ng/ml)	0.82 ± 0.53	5.66 ± 3.93*	0.78 ± 0.50	8.36 ± 3.33*
	DHEA-s (μg/ml)	2.65 ± 1.13	2.52 ± 0.83	2.55 ± 0.73	2.58 ± 0.73
	T (ng/ml)	0.44 ± 0.20	0.35 ± 0.18*	0.37 ± 0.14*	0.37 ± 0.15
	T livre (pg/ml)	2.57 ± 0.86	1.94 ± 0.62*	2.14 ± 0.62*	2.06 ± 0.60
		151.6±70.0	155.1±44.9	150.6±43.8	152.4±53.3*
		154.1±69.3	195.5±95.3	172.1±85.8	173.9±84.4*

Table IV – Continuation

Study	Concentration	Pre-training		Post-training	
		FP	LP	FP	LP
Parra et al. [23]	CK (U·L-1)	117.3±40.1	130.6±47.7	128.8±49.5	125.6±45.5*
		151.6±70.0	155.1±44.9	150.6±43.8	152.4±53.3*
	Myoglobin (µg·L-1)	105.5±43.9	129.1±56.3	107.9±41.2	115.0±48.7**
	LDH (U·L-1)	187.1±20.3	181.5±26.8	184.4±16.3	184.3±21.3**
	TNF-α (pg/mL)	4.8±1.4	4.8±1.0	4.6±0.9	4.7±1.1**
	CRP (mg/L)	0.6±0.4	0.5±0.3	0.5±0.3	0.5±0.3**
		0.5±0.3	0.5±0.3	0.5±0.3	0.5±0.3*
	AST (Ui/L)	22.8±4.2	23.4±4.7	23.8±4.2	23.4±4.3*
		23.1±4.7	24.3±5.1	23.8±4.0	23.7±4.6*

FP = follicular phase; LP = luteal phase; S = Strength; HC = Hormonal concentration; H = Hypertrophy; 5/3 = 5 maxims repetitions/3 minutes of rest; 10/3 = 10 maxims repetitions/3 minutes of rest; 5/1 = 5 maxims repetitions /1 minute rest; 5/1 = 5 maxims repetitions/1 minute rest; 10/3 = 10 maxims repetitions/3 minutes rest; E2 = Estradiol; P4 = Progesterone; SHBG = Sex hormone binding globulin; T= Testosterone; C = Cortisol; FSH = Follicle stimulating hormone; P= Progesterone; FSH = Follicle stimulating hormone; LH = Luteinizing hormone; DHEA- s= Dihydrotestosterone sulfate; CK = creatine kinase; LDH = lactate dehydrogenase; IL-6 = interleukin-6; TNF-α = tumor necrosis factor; CR = C-reactive protein; AST= aspartate aminotransferase; ALT = alanine aminotransferase; *; ** (p <0.05)

Table V presents the risk of bias in the studies through the ROBINS-I tool. Of the six studies, two studies were considered to have moderate risk [18,21] two were considered to have a critical risk of bias [19,22] and the other studies were considered to have a low risk of bias [20,23].

Table V – Risk analysis of bias by the tool ROBINS-1

Study	1	2	3	4	5	6	7	Total
Kraemer et al. [18]	PYes	PNot	PYes	PNot	PNot	PNot	PYes	3
Reis et al. [19]	PYes	PYes	PYes	PNot	PYes	PYes	PNot	5
Jonge et al. [20]	PNot	PYes	PNot	PNot	PNot	PYes	PNot	2
Elliott et al. [21]	PYes	PNot	PYes	PNot	PYes	PNot	PYes	4
Sung et al. [22]	PNot	PYes	PYes	PYes	PNot	PYes	PYes	5
Parra et al. [23]	PNot	PYes	PYes	PNot	PNot	PNot	PNot	2

P= Probably; 1 = Selection bias; 2 = Performance bias; 3 = Detection bias; 4 = Monitoring bias; 5 = Reporting bias; 6 = Bias due to lack of data; 7 = Bias in the selection of reported results

Discussion

This systematic review aimed to analyze the main findings of hormonal changes and strength performance in different phases of the menstrual cycle in experienced women undergoing ST. The six studies included different research questions,

measured different hormonal changes and strength performance at different stages of the menstrual cycle, and often reported varying results in the homonyms analyzed and increased muscle strength. From the six included studies (Table II), two did not present the training load and hormonal analyses [18,22], while the other four presented the training load and hormonal analyses [19–21,23].

Analysis of the studies [18–23] show either that the practice of ST with exercise protocols performed from 2 to 140 days caused a significant increase in estradiol, progesterone, testosterone, dihydrotestosterone sulfate, cortisol, and ammonia hormones, and blood markers of muscle damage and inflammation: creatine kinase. myoglobin, lactate dehydrogenase, interleukin-6, tumor-α necrosis factor, and C-reactive protein.

However, the findings of these experimental studies should be interpreted with caution as they were classified as uncertain risk of bias (Table V). Regarding interventions, two studies used ST isokinetic devices [18,20], two used dynamometers [21,22], and two used free weights with bars and washers [19,24]. In all studies there were hormonal variations after the intervention during the different phases of the menstrual cycle.

In addition, two of these studies [19,22] reported hormonal analyses before and after training during the follicular and luteal phase, while two studies [20,21] described hormonal analyses in follicular phase, medium and late without informing whether it was pre- or post-test. One study [23] presented the results of the hormonal analyses of pre-training in the middle of training and immediately after training in the times of 5 minutes, 120 minutes, 24 and 48 hours. Moreover, two of these studies did not present the maximum repetition (MR) tests used in the exercises [19,22] and the other four [18,20,21,23] described the MR tests used in the protocols.

In this sense, Kraemer *et al.* [18], Reis *et al.* [19], Jonge *et al.* [20], Sung *et al.* [22], and Parra [23] analyzed estrogen, progesterone, creatine kinase, and ammonia in women during menstrual cycle using an isokinetic dynamometer. The researchers reported that, after the ST intervention with MRI protocols, there was a significant increase in estrogen and progesterone levels during follicular phase for luteal phase (P < 0.05) and luteal phase (P < 0.01).

 Estrogen is a hormone with purported anabolic function, while progesterone has been linked to catabolic pathways [24]. Given these differences in hormonal functions, it is speculated that skeletal muscle performance may vary with changes in hormone production during the different phases of the menstrual cycle.

The current literature framework does not provide clear answers on this topic. However, Fridén *et al.* [25] reported an 11% increase in quadriceps and maximum voluntary isometric handgrip strength in the period of ovulation that coincided with follicular phase.

Similarly, Bambaeichi *et al.* [26] reported that isometric strength performance peaked during ovulation in follicular phase. These results suggest an association with ovarian hormones that have a notable influence on protein metabolism during

ST [27]. According to Oosthuyse and Bosch [28], the most frequent increases in muscle protein synthesis are related to the increase in training frequency. which favors the gain of muscle mass at rest during follicular phase.

Haines *et al.* [29] highlighted that mRNA protein synthesis α ER as well as cyclic expression of skeletal muscle mRNA D1 appear to be associated with activation and proliferation of skeletal satellite cells during follicular phase compared to luteal phase after an acute ST session [30,31].

However, other studies have not supported these findings as no changes in muscle strength have been found in the different phases of the menstrual cycle [28]. Gür [32] and Sterne [33] reported not having found differences in muscle torque in the concentric and eccentric stages between the menstrual, follicular, and luteal phases. The ambiguous evidence in the findings may be due to the use of different methods to estimate the phases of the menstrual cycle and the use of different muscle strength performance tests. A possible limitation of this evidence is that most studies have measured peak muscle strength values. However, in the practical context, the expression of maximum force rarely occurs, especially if we consider that the ST is commonly performed with submaximal loads (for example, 60 to 80% of 1MR).

This systematic review has some limitations that should be highlighted. First, measurements of female sex hormones were not performed to confirm the duration of the cycle from the beginning to the end of each phase. Second, none of the studies in this review reported whether participants measured hormone levels on the day of the test. It should be shown, given in more detail the three phases of a regular menstrual cycle. Thus, the chances of showing a relationship between hormone concentrations and muscle function would be increased. However, despite the limitations mentioned, the findings provided by the studies may contribute to elucidate hormonal changes and strength performance at different stages of the menstrual cycle in experienced women undergoing ST.

Conclusion

The studies analyzed in the present systematic review showed that ST can cause hormonal increases and improvements in muscle strength performance during the follicular phase compared to the luteal phase. It is suggested that the anabolic effects of ST are reduced in women with menstrual disorders. More studies will be needed to demonstrate the acute and long-term effects on skeletal muscle on hormonal responses to ST at different stages of the menstrual cycle.

Academic link
This study is linked to the final work of Pereira AS and Trindade AA of the Physical Education Course at Universidade Estácio de Sá (Petrópolis, RJ, Brazil).

Author's contribution
Research conception and design: Pereira AS and Trindade AA, Aguiar RS; **Data analysis and interpretation:** Aguiar RS, Castro JBP, Silva MO, Fernandes ADO; **Writing of the manuscript:** Pereira AS and Trindade AA, Castro JBP; **Critical review of the manuscript for important intellectual content:** Castro JBP, Vale RGS, Aguiar RS

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