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ORIGINAL ARTICLE

Menstrual cycle-based undulating periodized program effects on body composition and strength in trained women: a pilot study

Les effets d'un programme de périodisation ondulante, basé sur le cycle menstruel, sur la composition du corps et la force des femmes pratiquantes de musculation: une étude pilote

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KEYWORDS
Resistance training ;
Bodybuilding ;
Sports nutrition ;
Sex hormones ;
Body fat

Summary
Objective. — To evaluate changes in body composition and strength after menstrual cycle-based or traditional undulating resistance training (RT) programs in women.
Equipment and methods. — Ten resistance-trained and eumenorrheic women (26.6 ± 3.0 years; 164.7 ± 6.5 cm; 62.3 ± 6.8 kg) were randomly assigned to a menstrual cycle-based periodized upper/lower training ($n = 5$, MC) or an undulating training group ($n = 5$, UT) for 8 weeks. The number of repetitions and load were adjusted to each phase of the menstrual cycle. Fat free

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mass (FFM) and fat mass (FM) were evaluated by dual x-ray absorptiometry (DXA); maximal strength was assessed by the 1 repetition maximum (1-RM) test in the back squat (SQ) and bench press (BP); and muscle power was assessed by the countermovement jump (CMJ) test using a jump contact mat.
Results. — A significant increase in FFM was observed for UT (1.4 ± 0.9 kg, $P = 0.043$, ES = 0.58) with no difference in MC (1.7 ± 1.8 kg, $P = 0.080$, ES = 0.25). No changes in FM were observed for either condition (MC: 0.9 ± 1.2 kg, $p = 0.225$, ES = 0.21 and UT: 0.5 ± 1.0 kg, $P = 0.345$, ES = 0.13). Strength increases were observed for both MC an UT in the BP (8.9 ± 3.4 kg, $p = 0.042$, ES = 0.87 and 5.0 ± 1.8 kg, $p = 0.039$, ES = 0.67, respectively) and SQ (15.3 ± 9.2 kg, $P = 0.043$, ES = 0.93 and 16.4 ± 7.6 kg, $P = 0.042$, ES = 1.38, respectively). CMJ showed differences in MC (4.0 ± 2.5 cm, $P = 0.043$, ES = 1.12). We observed a between-group difference in BP ($P = 0.041$) favoring MC; no other interactions were found.
Conclusions. — Eight weeks of a menstrual cycle-based periodized training combined with a hyperenergetic diet versus a non-matched undulating RT program have a differential impact on body composition and muscular adaptations in trained women.

MOTS CLÉS
Musculation ;
Body building ;
Nutrition du sport ;
Hormones sexuelles ;
Masse grasse

Résumé
Objectifs. — Évaluer les différences de changement dans la composition du corps et la force entre un programme de musculation basé sur le cycle menstruel et un programme traditionnel de périodisation ondulante chez la femme.
Équipement et méthodes. — Dix femmes euménorrhéiques et pratiquantes de musculation (26,6 ± 30 ans; 164,7 ± 6,5 cm; 62,3 ± 6,8 kg) ont été aléatoirement assignées à un entraînement de périodisation alternée basé sur leur cycle menstruel ($n = 5$, MC) ou à un entraînement classique de périodisation ondulante ($n = 5$, UT), pendant 8 semaines. Le nombre de répétitions et la charge ont été ajustées selon les phases du cycle menstruel. La masse non grasse (FFM) et la masse grasse (FM) ont été évaluées par absorption biphotonique à rayons X (DXA); la force maximale a été déterminée sur le test de répétition maximale (1-RM) avec la squats barre (SQ) ou en développé-couché (BP); la force explosive a été déterminée par le test du Countermovement Jump (CMJ) en utilisant un tapis de saut.
Résultats. — Une hausse significative de la masse non grasse (FFM) a été observée pour UT (1,4 ± 0,9 kg, $p = 0,043$, ES = 0,58) contre aucune différence pour MC (1,7 ± 1,8 kg, $p = 0,080$, ES = 0,25). Aucun changement n'a été observé pour la masse grasse (FM) dans les deux cas (MC: 0,9 ± 1,2 kg, $p = 0,225$, ES = 0,21 and UT: 0,5 ± 1,0 kg, $p = 0,345$, ES = 0,13). Une augmentation de la force a été observée pour MC et UT: BP (respectivement 8,9 ± 3,4 kg, $p = 0,042$, ES = 0,87 and 5,0 ± 1,8 kg, $p = 0,039$, ES = 0,67) et SQ (respectivement 15,3 ± 9,2 kg, $p = 0,043$, ES = 0,93 and 16,4 ± 7,6 kg, $p = 0,042$, ES = 1,38). Le CMJ a montré des différences pour MC (4,0 ± 2,5 cm, $p = 0,043$, ES = 1,12). Nous avons observé une différence de BP entre les groupes ($p = 0,041$) en faveur de la MC; aucune autre interaction n'a été trouvée.
Conclusions. — Huit semaines d'entraînement de périodisation basé sur le cycle menstruel, associé à un régime hyperénergétique vs. un entraînement de musculation à périodisation ondulante ne le prenant pas en compte ont un impact différent sur la composition du corps et les évolutions musculaires chez les pratiquantes de musculation.

1. Introduction

It has been speculated that hormonal fluctuations throughout the menstrual cycle may influence athletic performance; however, inter- and intra-individual variability has led to contradictory results [1,2]. The menstrual cycle lasts approximately 26 to 35 days; in some women, it may extend to between 24 and 38 days [3]. For women who do not use any type of contraceptive [4], the first day of bleeding marks the beginning of the cycle, and the day before the first day of bleeding in the next cycle marks the end. During this time interval, a series of physiological changes occur that can be divided into five phases: the early follicular, mid follicular phase (FP), ovulation (OV) and the early luteal and late luteal phase (LP).As its name implies, the FP is the initial phase, in which the formation and proliferation of follicles occurs. This phase begins with increases in follicle-stimulating hormone (FSH) and luteinizing hormone (LH), which control hormonal production in the ovary [5]. The ovulation process occurs approximately 12 hours after the initial increase in LH [6]. During the LT phase, the granular cells start to accumulate a yellow pigment called lutein, which, together with other cells, forms the corpus luteum [7].

Significant alterations in hormones occur during the various phases of the menstrual cycle. Of note, these changes are associated with changes in appetite control and, during the premenstrual phase, many women are prone to excessive energy intake [8] as well as variations in emotional processing and behavioural memory [9,10]. Other studies have focused on the relationship between the menstrual cycle and stress and haemodynamic and cardiovascular responses [11,12], and on how it can influence metabolism during exercise [13]. In addition, recent studies have reported increased cortisol concentrations during the LP in women subjected to laboratory-induced mental stress [14]. Despite the potential for such alterations to affect physical performance, how and to what extent the different phases of the menstrual cycle influence exercise adaptations remains equivocal.

Currently, several studies show that programmed strength training improves flexibility, strength, muscle hypertrophy and body fat percentage in females [15]. Likewise, undulating or nonlinear training offers improvements at the neuromuscular and body composition level similar to those of traditional training [16], and a greater increase in muscle thickness has been reported in men [17]. Notwithstanding, emerging research has compared the effects of FP and LT phases on strength-related variables. For example, maximum isometric strength, muscle diameter, muscle fiber composition and fiber diameter were analyzed before and after a training intervention [18]. The volume of the biceps brachii muscle evaluated by magnetic resonance imaging and the isometric force of the elbow flexors [19], the body mass index and the maximum isometric force [20], and even the training frequency in the FP or LT phase evaluating the force [21] and the cross sectional area [22]. However, there are no data that indicate different repetition ranges or intensity levels are superior to others in the different phases of the menstrual cycle. Therefore, the objective of this pilot study was to investigate the effects of periodization of resistance training (RT) based on the menstrual cycle compared to a fixed undulating program on body composition and strength levels in resistance-trained women. We hypothesized that matching each phase of the menstrual cycle with different loads through the application of undulating training would generate superior improvements in strength and fat-free mass (FFM) in trained women.

2. Material and methods

2.1. Participants

Non-probability sampling (convenience sampling) was employed, as often used in pilot studies [23]. Fourteen women (age 26.6 ± 3.0 years; stature 164.7 ± 6.5 cm; weight 62.3 ± 6.8 kg; BMI 23.0 ± 1.8 kg·m^2), with regular menstrual cycles (at pre-test 30 ± 2 days) and more than two years of continuous resistance training experience, volunteered to participate in the study. Participants who used contraceptives of any type or had a menstrual cycle disorder (e.g., oligomenorrhea or amenorrhea) or polycystic ovary syndrome (PCOS) were excluded. In addition, participants who had consumed ergogenic aids (e.g., anabolic androgenic steroids) during the previous 2 years and/or consumed any type of nutritional supplement during the program were excluded. The participants were informed of the possible risks of the experiment and signed an informed consent form. All participants agreed to follow the prescribed training and diet programs during the 8-week intervention period and to refrain from any other physical activity or dietary practices other than that prescribed herein. The study was developed in accordance with the ethical guidelines of the World Medical Association Declaration of Helsinki and approved by the ethics committee at the University of Malaga (code: 38-2019-H). (Fig. 1) displays a flowchart of the data collection process as per the Consolidated Standards of Reporting Trials (CONSORT).

2.2. Procedures

The participants were randomly assigned to a menstrual cycle-based (MC) group or to an undulating training (UT) group. While the UT group began their training and diet at the end of the familiarization phase, the MC group did so based on the ovulation phase as determined by a qualitative analysis of LH in urine, which has been validated as an accurate measurement method [24], and is safe and non-invasive. To conduct the assessment, test strips were used starting 9 days from the first day of menstruation, and the training and diet the day were initiated after a obtaining a positive test result.

2.2.1. Training familiarization phase

Prior to the main intervention, all participants completed 3 weeks of familiarization in which loads were adjusted according to each phase of training, and a metronome was used to control the prescribed repetition cadences. Additionally, instructions for organizing and developing the nutritional intervention were given.

2.2.2. Nutritional intervention

To prevent low energy availability and consequent changes in the menstrual cycle, subjects were prescribed an intake of 45 kcal kg^{-1} fat-free mass (FFM), exceeding the 30 kcal kg^{-1} FFM implemented in some previous studies. [25]. The prescribed protein intake was 2 g kg^{-1} d^{-1}, which provided a buffer to help ensure consumption of the recommended 1.7 g kg^{-1} d^{-1} [26]. The prescribed dietary fat intake amounted to 1 g kg^{-1} d^{-1} and the remaining calories were consumed as carbohydrates.

To confirm that the prescribed intake was met, the participants recorded their daily macronutrient consumption via a software application (MyFitnessPal, LLC, CA, USA); this tool has been validated as a viable method for evaluating energy and macronutrients [27]. To enhance accuracy of reporting and adherence, a sports nutritionist with experience in RT instructed the participants on the proper use of the application and provided dietary coaching throughout the study period.

2.2.3. Training program

Both groups performed an upper/lower split-body routine that consisted of 4 weekly sessions with 72 hours of recovery between body regions during the 3 weeks of familiarization and the 8-week intervention period. The UT program

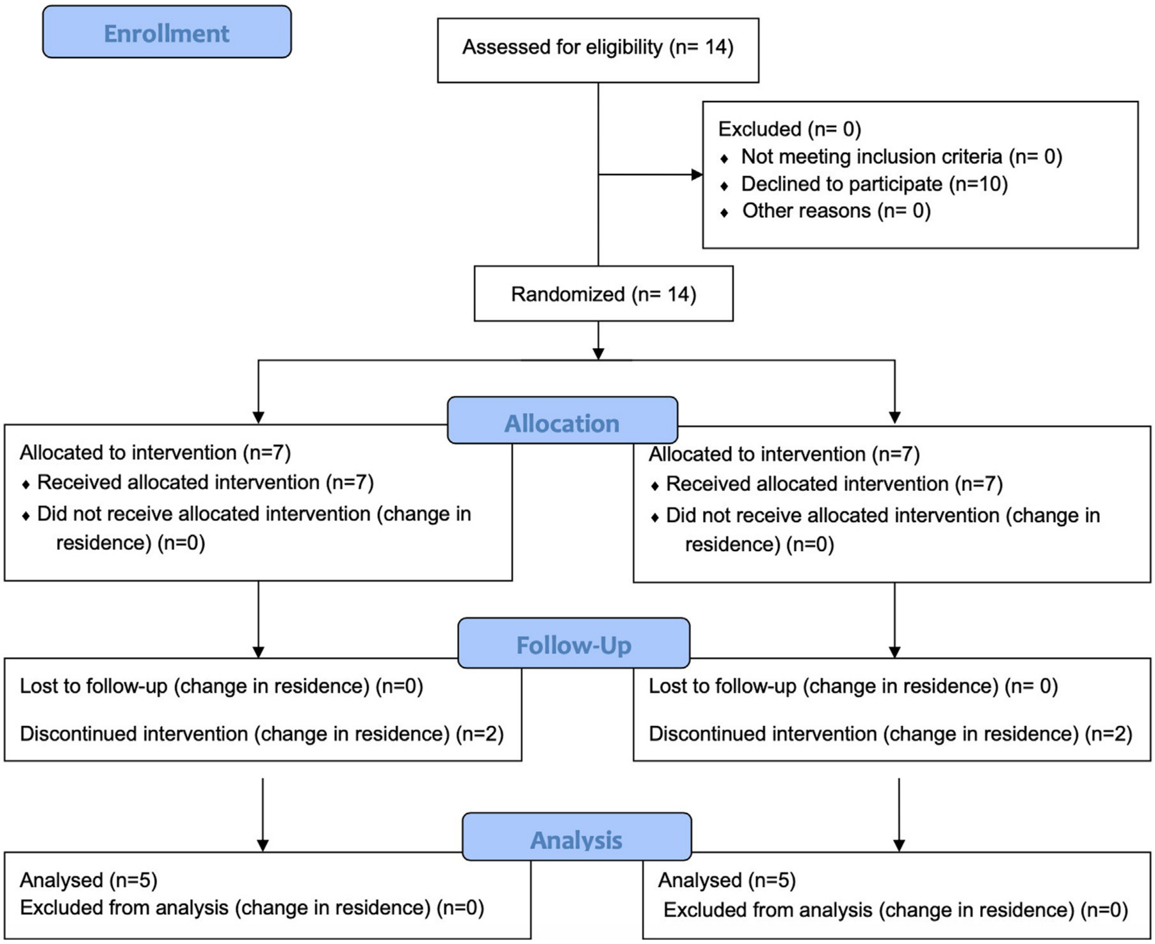

Figure 1 Consort flowchart of the study.

involved nonlinear training divided into 4 phases: the first week coincided with a strength phase, the second with a hypertrophy phase, the third with a muscular endurance phase and the last week of the first month with a recovery period in which the total volume was reduced (series x repetitions x load). The same pattern continued for the ensuing 4 weeks. The training scheme, intensity, rest periods and cadences were adjusted to target each training approach, as shown in (Fig. 2).

The MC program began during the hypertrophy week and coincided with the ovulation phase, beginning the day after obtaining a positive LH test. The FP was matched to the strength phase, and the LP was matched with the muscular endurance phase. The pre-menstrual period was matched to the recovery phase considering that reduced physical performance [28], impaired sleep recovery, cramps and anxiety have been reported during this portion of the cycle [29,30]. During the intervention, the participants in both groups were supervised by an expert in RT who monitored and controlled the load during each training session and made any necessary adjustments to the routine.

2.3. Measurements

2.3.1. Body composition

Body composition was measured seven days after menstruation in both the pre- and post-intervention periods so as to avoid the potential for body mass increase caused by hormonal-induced water retention [31,32]. Total body and regional body composition were estimated using dual-energy x-ray absorptiometry (DXA). Each subject was scanned by a certified technician, and the distinguished bone and soft tissue, edge detection, and regional demarcations were analyzed by computer algorithms (software version APEX 3.0, Hologic QDR 4500, Bedford, MA). For each scan, participants wore sport clothes and removed all materials that could attenuate the X-ray beam including jewelry items and underwear containing wire. Calibration of the densitometer was checked daily against a standard calibration block supplied by the manufacturer. The coefficient of variation values was less than 1.5% for all whole body and segmental body composition measurements including fat mass (FM) (%), FM (g), FFM (g) and total body mass (g).

2.3.2. Countermovement jump (CMJ) test

Each subject performed two countermovement jumps (CMJ) on a jump mat (Smart Jump; Fusion Sport, Coopers Plains, Australia) with a rest interval of 1 min between each attempt (highest value was computed). The test was performed after instructions on proper jump execution during familiarization (3—5 attempts), based on previous recommendations by our laboratory [33]. Instructions emphasized that the

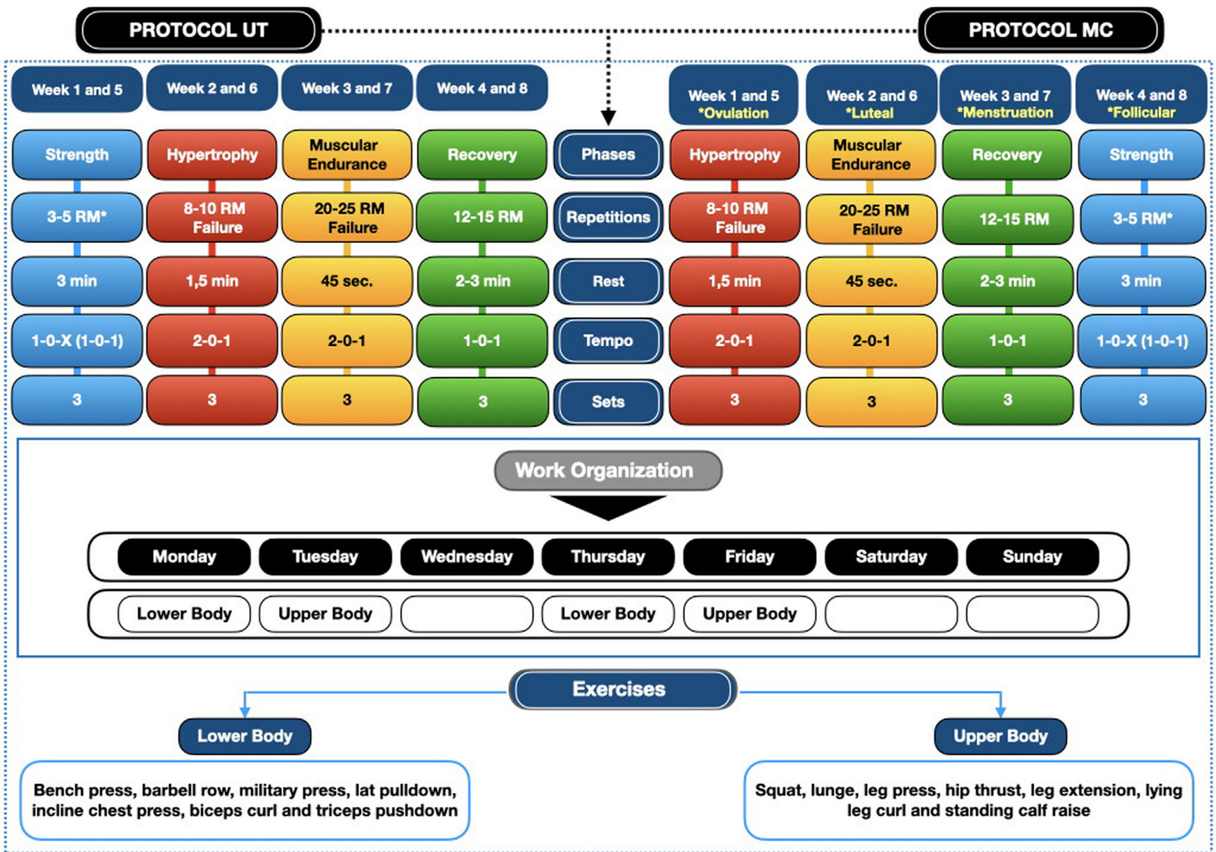

Figure 2 Schematic representation of the training program. 1-0-1 = a second eccentric phase, zero isometric and one second in the concentric. All exercises were performed at a cadence of 1-0-X, except squats and deadlifts, which were performed at 1-0-1 to control the risk of injury. RM = repetition maximum; * 1 or 2 reps before the failure; ** before the failure. Training phases (strength, hypertrophy and muscular endurance) and goal repetitions according to established criteria by National Strength and Conditioning Association.

movement should be performed without interruption from the beginning to the end of the jump.

2.3.3. Repetition maximum (RM) test

The one repetition maximum (1RM) was tested for squat (SQ) and bench press (BP) at the beginning (baseline) and end of the intervention. The test was performed on a Smith Machine (Gervasport, Madrid, Spain) after refraining from any exercise other than activities of daily living for at least 48 h before each test. Women performed a general warm-up (7 to 10 min of low-intensity cardiovascular exercise in treadmill) prior to testing. Briefly, all participants commenced the 1RM assessment with sets of increasing loads estimated to be ~40% 1RM (10 to 12-REPs as specific warm-up), ~60% 1RM (2 to 3-REPs), ~80% 1RM (2 to 3-REPs), and ~90% 1RM (1-REP), followed by sets of one repetition until the load could not be lifted through the entire range of motion [34]. The participants rested for ~3—5 minutes between each trial, and performed the 1RM SQ test before the 1RM BP with an inter-set rest period of 7 min. Research assistants monitored participants' performance to ensure successful movements and that all standard procedures were being followed, according to the laboratory methods as described by [33].

2.4. Statistical analysis

The data are expressed as the mean and standard deviation. The change in the variables relative to the baseline was calculated, and the 95% confidence intervals of the means are presented. The normality of the data and the homogeneity of the variances were verified with the Shapiro-Wilk and Levene tests, respectively. The difference between the pre-test and the post-test scores for each group was established with the Wilcoxon Signed Rank Test, and the effect size was established with Hedges' g test; the comparison (pre vs post-test) is presented in a Cumming estimation plot [35]. The difference (Δ) between the groups was determined with the two-sided permutation t-test. The significance level adopted for all tests was 0.05. The statistical analysis was performed using IBM SPSS version 25 (IBM Corp., Armonk, NY, USA).

3. Results

Fourteen women were selected for participation based on the inclusion/exclusion criteria defined in the study design. From this sample, seven women were assigned to each study group. Two participants in each group were

Table 1 Baseline characteristics of study participants.

	MC (*n* = 5)	UT (*n* = 5)	*P*
Stature (cm)	165.4 ± 8.5	163.9 ± 4.5	0.917
BM (kg)	63.0 ± 9.1	61.6 ± 4.4	0.754
BMI (kg m^{-2})	22.9 ± 2.1	23.0 ± 1.8	0.917
FM (kg)	18.3 ± 3.6	17.1 ± 3.7	0.602
FFM (kg)	44.1 ± 5.5	43.9 ± 1.9	0.917
BP (kg)	33.5 ± 10.2	39.5 ± 6.5	0.340
Squat (kg)	64.5 ± 15.4	63.5 ± 9.4	0.834
CMJ (cm)	20.8 ± 3.5	24.5 ± 2.2	0.175

MC: menstrual cycle-based periodized upper/lower training group; UT:, undulating training group; BM: body mass; BMI: body mass index; FM: fat mass; FFM: fat-free mass; BP: bench press; CMJ: countermovement jump; P: for the independent-samples *t* Test.

excluded because of non-compliance, leaving five participants per group (Fig. 1). There were no between-group differences in the participants' characteristics at baseline (Table 1).

In regard to body composition, FM tended to increase with a small effect in both MC (0.9 ± 1.2 kg, $P = 0.225$, ES = 0.21) and UT (0.5 ± 1.0 kg, $P = 0.345$, ES = 0.13), but results did not reach statistical significance. FFM significantly increased in UT (1.4 ± 0.9 kg, $P = 0.043$; ES = 0.58) but increases did not reach statistical significance in MC (1.7 ± 1.8 kg, $p = 0.080$, ES = 0.25); no between-group differences were observed ($P = 0.692$) (Table 2, Fig. 3).

Regarding upper limb strength in the 1RM BP, MC displayed significant post-study increases and a large effect (8.9 ± 3.4 kg, $P = 0.042$, ES = 0.87) whereas UT showed significant increases with a medium effect (5.0 ± 1.8 kg, $P = 0.039$, ES = 0.67). Between-group differences were observed in the 1RM BP, with results favoring MC ($P = 0.041$). In regard to lower limb strength, both MC and UT demonstrated significant increases with a large effect size in the 1RM squat (15.3 ± 9.2 kg, $P = 0.043$, ES = 0.93 y 16.4 ± 7.6 kg, $p = 0.042$, ES = 1.38, respectively), with no differences between groups ($P = 0.802$). In the CMJ, only the MC group showed statistically significant improvements with a large effect (4.0 ± 2.5 cm, $P = 0.043$, ES = 1.12) whereas UT did not demonstrate statistically significant changes (1.2 ± 2.0 cm, $P = 0.225$, ES = 0.35); no significant between-group differences were noted ($P = 0.092$) (Table 2, Fig. 4).

4. Discussion

To our knowledge, this is the first study to investigate the effects of matching different phases of the menstrual cycle with targeted training goals on measures of body composition and strength. The study produced several novel findings. 1) UT showed statistically significant increases in FFM whereas gains in MC did not reach statistical significance. However, the absolute changes favored MC (1.7 kg vs 1.4 kg, respectively), calling into question the practical meaningfulness of these findings. 2) Both groups showed improvements in the 1RM for BP and SQ; the absolute changes in the BP favored MC, with results showing statistically greater differences compared to UT. 3) Only the MC group displayed significant improvements in CMJ and, although no statistical differences were observed between groups, the effect size markedly favored MC over UC (1.12 vs. 0.35, respectively).

Some authors have observed greater gains in FFM and strength when training is based on the post-menstrual phase that coincides with the FP [36], although others have not observed neuromuscular differences throughout different phases of the cycle [37]. A higher workload in the FP compared to the LP has also been reported [38]. Moreover, increased pulmonary ventilation and higher oxygen absorption level at rest [39,40], reduced rates of gluconeogenesis and glycolysis, increased lipid production [41], and greater utilization of free fatty acids as an energy source and reduced respiratory quotients [42] have been observed during the LP.

Previous research has focused on comparing the effects of different phases of the menstrual cycle on performance [43] or muscle hypertrophy [19]. Improvements in muscle hypertrophy and strength have been found when RT training is performed more frequently in the FP compared to the LP [1]. However, in our study, the frequency of training by muscle group was similar during all phases of the menstrual cycle, and no differences were found between groups. In addition, undulating training has shown to have positive effects in various studies on both performance and muscle hypertrophy [17,44]; however, these investigations were carried out in men. Our results are consistent with these reports, considering that undulating periodization, independent of the menstrual cycle, resulted in increases in FFM, and measures of upper and lower body strength. However, it should be noted that other studies have obtained more favorable results for linear periodization in different populations [45].

Table 2 Results of body composition and strength levels of the study groups.

	MC			UT			Differences (MC−UT)	
	Δ	*P*	ES	Δ	*P*	ES	Δ−Δ	*P*
FM (kg)	0.9 ± 1.2 (−0.6, 2.3)	0.225	0.21	0.5 ± 1.0 (−0.8, 1.8)	0.345	0.13	0.36 ± (−1.27, 1.99)	0.611
FFM (kg)	1.7 ± 1.8 (−0.5, 3.9)	0.080	0.25	1.4 ± 0.9 (0.3, 2.5)	0.043	0.58	0.34 ± (−1.86, 2.53)	0.692
BP (kg)	8.9 ± 3.4 (4.7, 13.1)	0.042	0.87	5.0 ± 1.8 (2.8, 7.2)	0.039	0.67	3.90 ± (−0.31, 8.11)	0.041
Squat (kg)	15.3 ± 9.2 (3.9, 26.7)	0.043	0.93	16.4 ± 7.6 (6.9, 25.9)	0.042	1.38	−1.10 ± (−13.43, 11.23)	0.802
CMJ (cm)	4.0 ± 2.5 (0.9,7.2)	0.043	1.12	1.2 ± 2.0 (−1.3, 3.7)	0.225	0.35	2.85 ± (−0.48, 6.18)	0.092

MC: menstrual cycle-based periodized upper/lower training group; UT: undulating training group; FM: fat mass; FFM: fat-free mass; BP: bench press, CMJ: countermovement jump; ES:effect size; P: for the independent-samples *t* Test.

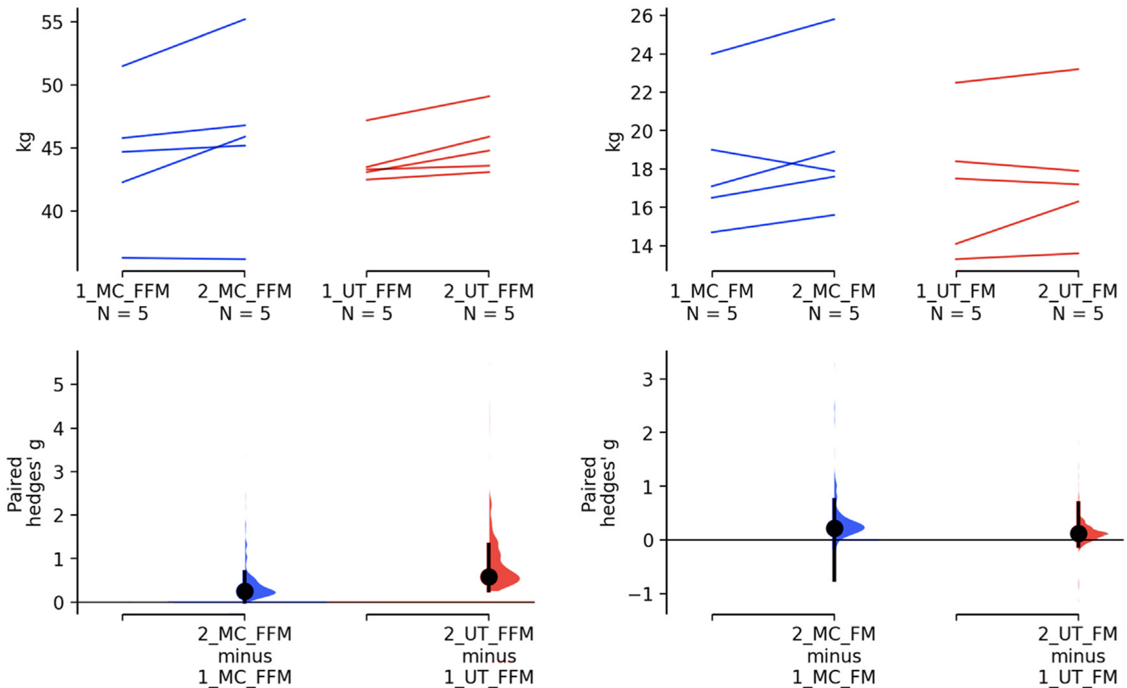

Figure 3 Results pre-test and post-test for FM and FFM. The paired median difference for two comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each paired set of observations is connected by a line. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars.

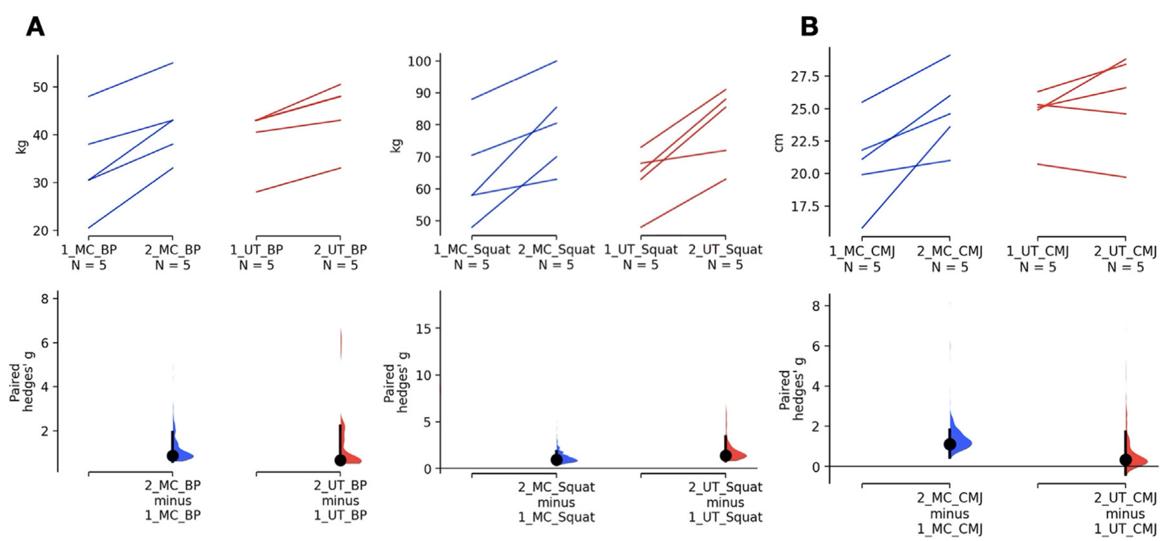

Figure 4 Results pre-test and post-test for BP and Squat (A) and CMJ (B). The paired median difference for two comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each paired set of observations is connected by a line. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars.

It is worth noting the complexity of our study, since each phase of the cycle can vary in length among different women or from month to month in the same woman. In addition, stress, diet and type of exercise can differentially affect individuals and thus can modify the secretion of reproductive hormones. Therefore, with the exception of the beginning of OV, which was determined using urine testing strips, the timing of the other phases was approximated. Importantly, our small sample size limits the ability to draw strong inferences on the topic, and thus this study should be considered as a preliminary work that warrants further investigation.

5. Conclusions

An 8-week undulating program based on the different phases of the menstrual cycle increases strength and FFM in trained eumenorrheic women, although improvements are similar to that achieved in a traditional undulating program. There did appear to be a benefit of the menstrual cycle tailored program on BP and CMJ performance, although our small sample impaired the ability to determine whether these results were due to chance. Future studies should seek to investigate the topic employing a larger sample.

Disclosure of interest

The authors declare that they have no competing interest.

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