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Menstrual cycle on internal and external load in amateur women CrossFit players

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Abstract

Background: Female physical performance can be influenced by perceived, physiological, and physical factors, making it an important field for further research.
Aims: The purpose of this study was to analyze the effects of the menstrual cycle (MC) on the cardiovascular and neuromuscular load of amateur women athletes in CrossFit® during real training situations.
Methods: Resistance-trained CrossFit® athletes (without oral contraception) and eumenorrheic women participated in this study (age: 29.6 ± 4.06 years; height: 1.59.3 ± 0.06 m; body mass: 61.22 ± 4.59 kg). A cross-sectional, descriptive study was conducted to evaluate heart rate variability (rMSSD), upper-body strength, muscular endurance, and power performance. The data were analyzed using a one-way repeated-measures ANOVA and the nonparametric Friedman test to assess significant differences among the follicular, ovulatory, and luteal phases for all assessments. The significance was set at $p \leq 0.05$.
Result: Results revealed no significant differences between the menstrual cycle phases in performance: (HRV RMSSD: H: 0.830, *p*: 0.443, η2: 0.038), (Push up test: H: 0.041, *p*: 0.959, η2: 0.002), (countermovement jump: H: 11.921, *p*: 0.050, η2: 0.362), (rate force development CMJ: H: 1.242, *p*: 0.299, η2: 0.056), (squat jump: H: 0.439, *p*: 0.648, η2: 0.020), (rate force development SJ: H: 1.703, *p*: 0.194, η2: 0.075), (isometric mid-thigh pull: H: 0.019, *p*: 0.981, η2: 9.132×10^{-4}). Performance is not altered during the MC in female CrossFit® trained athletes.
Conclusion: These findings demonstrate that the menstrual cycle does not significantly influence internal and external training load, heart rate variability, or strength and power performance in this population.

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INTRODUCTION

The CrossFit® workouts are described as an alternative to functional training with programming based on varied movements performed at high intensity. This training method includes weightlifting, gymnastics and athletic conditioning (Fields et al., 2018; Fry et al., 2006; Pilis et al., 2019) and leads to hormonal responses (Cadegiani et al., 2019), metabolic changes (Tibana et al., 2018) and physiological (Forte et al., 2022) responses in male and female athletes. On the other hand, this training program is increasingly popular worldwide (Lichtenstein & Jensen, 2016).

Therefore, among female athletes, the menstrual cycle represents a key physiological factor that may influence training responses and performance. Fluctuations in ovarian hormones across the menstrual cycle have been associated with changes in neuromuscular function (Dasa et al., 2021), cardiovascular regulation, substrate utilization, and perceived exertion. On the other hand, CrossFit®, similar to exercise-induced muscle damage, is an aspect linked to excessive mechanical stress that often surpasses skeletal muscle capacity. This is characterized by inflammation and

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structural disruption, leading to muscle swelling, soreness, and decreased contractile strength (Peake et al., 2017). For this reason, it is necessary to further investigate these aspects for a comprehensive understanding of athlete's performance (Emmonds et al., 2019), it is important 'to control' for the menstrual cycle, which is characterized by cyclical variations in female sex hormones (Arenas-Pareja et al., 2023). Specifically, each phase of the cycle could affect participants' physical fitness (Emmonds et al., 2019).

These responses compromise athletic performance and recovery in athletes, potentially exacerbating inflammation and neuromuscular fatigue (Arenas-Pareja et al., 2023; McNulty et al., 2020). In this case, estrogen plays a role in metabolic regulation and anabolic effects (Lowe et al., 2010), potentially impacting high-intensity performance, strength, and power. Additionally, the luteal phase between ovulation and the next period involves progesterone produced by the corpus luteum, promoting thickening of the womb lining in preparation for receiving a fertilized egg (Mihm et al., 2011). On the other hand, physical performance changes throughout the Menstrual Cycle (MC) due to hormone regulation, muscle activation, and substrate metabolism (Smith et al., 2002). Therefore, the MC, which lasts between 20 and 36 days (Carmichael et al., 2021; Hawkins & Matzuk, 2008) consists of various phases: menstruation, follicular phase, ovulation, and luteal phase. The early follicular phase (EFP) is characterized by low serum progesterone and estrogen concentrations. The late follicular phase (LFP) sees low progesterone levels a longside high estrogen concentration ending with an increase in luteinizing hormone (Farage et al., 2009). These reasons could justify this study because responses to physical training can vary depending on each phase of the menstrual cycle; exercise performance might be reduced during the early follicular phase compared to the ovulatory and luteal phases (McNulty et al., 2020).

Additionally, among the most common measures of sports control, heart rate variability (HRV/ RMSSD Root Mean Square of Successive Differences)(Dong, 2016) is a tool used to understand the perception of effort, recovery, adaptability and assess training status after a workout through the use of wearable devices (Dong, 2016; Tibana et al., 2019). Similarly, neuromuscular performance (external load) has been previously described (Mora-Serrano et al., 2024; Schlegel & Křehký, 2022) suggesting that strength tests conducted on innovative force plate systems could offer a thorough understanding of upper body (handgrip strength, push up test) and lower-body (CMJ, IMTP)(Grgic et al., 2022) neuromuscular performance capabilities of female athletes in relation to the menstrual cycle (Beckham et al., 2013; Carmichael et al., 2021).

Addressing this gap is essential to inform evidence-based training strategies and avoid unsupported assumptions regarding phase-based training adjustments. Finally, studying the effect of MC phases on the physical performance of female amateur CrossFit® athletes is a useful component significant to explaining the evidence base in sports science (Dominski et al., 2021). Thus, the purpose of this study was to analyze the effects of the MC on the internal and external load of amateur women CrossFit® athletes in a real training situation.

METHOD

Research Design

This study used a repeated-measures design to investigate differences in cardiovascular (Heart Rate Variability "HRV-RMSSD") and neuromuscular performance: handgrip strength (HGS), push-up test (PUT), countermovement jump test (CMJ), squat jump test (SJ), and isometric mid-thigh pull (IMTP) during CrossFit® training across three phases of the menstrual cycle. The phases evaluated were: the follicular phase (FP), ovulation phase (OP), and luteal phase (LP), which represent the main physiological events of the menstrual cycle (Janse de Jonge, 2003). Each participant completed one testing session were separated by a minimum interval of 7 days, ensuring adequate recovery and minimizing potential carryover effects. The order of the menstrual cycle phases was randomized for each athlete to reduce order effects (three participants started in FP, Six in OP, and six in LP)

Participant

Fifteen female CrossFit® athletes volunteered to participate in this study. The average age, height, weight, and BMI were: 29.6 ± 4.06 years, 1.59 ± 0.06 cm, 61.22 ± 4.59 Kg, and 23.6 ± 1.85, respectively. Participants were classified as amateur CrossFit® athletes, defined as individuals who engaged in CrossFit® training at least 3 sessions per week for at least 3 consecutive months. Participants were included if they had at least thirteen months of strength training (ST) experience (13 ± 5 months of experience in this sample). They were familiar with the *Workout of the Day* (WOD) exercises in CrossFit®. During this study, participants were encouraged to maintain their training routines without participating at the elite, amateur or professional competitive level. Three weeks before the onset of the experimental protocol, informed consent was obtained from each participant.

To be able to participate in this study, they also had to meet the following inclusion criteria: (1) All participants had a regular menstrual cycle for the three months previous to the experiment (27 ± 2 days, range = 24-31 days) and were considered as eumenorrheic. (2) Participants were not using any form of hormonal contraception for at least the three months before the experiment. (3) All participants were free from any type of menstrual disorders (e.g., amenorrhea, dysmenorrhea or symptoms associated with pre-menstrual syndrome), (4) had no musculoskeletal injuries in the three months previous to the investigation (medical diagnosis) and (5) were not taking drugs or dietary supplements during the duration of the experiment (6) performed strength training and CrossFit® at least three times a week in the last three months, and (2) had more than 1 year of experience in CrossFit®. The exclusion criteria were (1) having some muscular or joint alteration, (2) not having a regular menstrual cycle, (3) absence at the test on the designated day, (4) experiencing any medical condition, or injury during the 28 days of this study.

To determine the appropriate sample size for female CrossFit® athletes, we conducted an a priori power analysis using G*Power (version 3.1.9.4). approximating the non-parametric test with a repeated-measures ANOVA. Assuming a medium-to-large effect size ($f = 0.40$), $\alpha = 0.05$, three measurements. As the assumption of normality was violated, differences between phases were analyzed using the Friedman test. A total sample of 15 participants, the estimated statistical power was approximately 0.70

Procedures

Two weeks before the onset of the experiment, athletes performed three familiarization sessions with the testing protocol to minimize any learning effects during the study. All participants completed a twelve-minute standardized warm-up. This warming included dynamic flexibility exercises; muscular endurance exercises were performed in an increasing order of intensity. Subsequently, anthropometric measurements were assessed but were not used as covariates in the analysis. A stadiometer (Seca Corp., Chino, CA, USA) was used to measure height, and for body mass, body fat, and average lean muscle weight, an InBody 270 digital scale (Seoul, South Korea) was employed.

Heart Rate Variability (HRV- RMSSD)

To quantify the HRV (rMSSD), participants were measured in the morning (6 am) for 5 minutes in the supine position. External factors were controlled throughout the study process thanks to the reports in the app and the feedback exchanged between athletes and coaches. Data collection occurred when athletes rested in a quiet environment, using the Polar H10 (1000 Hz) (Schaffarczyk et al., 2022) was connected via Bluetooth to a Smartphone application known as "Elite HRV" (Version 5.5.1, Asheville, NC, USA) on an iPhone (13th generation, Apple Inc., Cupertino, CA, USA). From Elite HRV (Vondrasek et al., 2023) The data displayed in the app were recorded for analysis of the variation in time between heartbeats. The rMSSD (i.e., root mean square of successive R-R intervals), was selected to reflect alterations in vagal modulation and was chosen because of its greater reliability in demonstrating parasympathetic activity (Al Haddad et al., 2011).

Handgrip Strength (HGS)

Handgrip testing was performed between the left and right sides for three trials on each side (Agtuahene et al., 2023). Athletes were asked to squeeze maximally for 5 seconds, and the results were recorded in kilograms (kg). Was assigned dominance to the higher average of the two sides. Grip strength was assessed using a hand dynamometer (Hand dynamometer, Camry Instrument Company, China).

Push Up Test (PUT)

The participants started the push-ups with their arms extended (upwards), forearms and wrists in pronation, and feet at a biacromial width (shoulders). The kinetic parameters of the push-up test were measured using a force platform (K-Force, Kinvent Inc., Montpellier, France) at 1000 Hz. Before each test, participants performed 10 minutes of warm-up exercises under the supervision of a researcher. After the warm-up, participants performed more push-ups in 10 seconds, following the (K-Force, Kinvent) protocol. They were directed to execute the test rapidly and to their maximum capacity. Participants were positioned in 90 degrees of flexion of the shoulder, elbow, trunk, and hip in full extension, with body weight on knees, and feet together on the ground (Öztürk et al., 2023)

Squat Jump (SJ) - Countermovement Jump (CMJ) Test

Athletes completed one set of three jumps at a selected foot position. They were instructed to jump as explosively as possible to achieve maximal height. A "3, 2, 1" jump countdown was used for each trial. During the SJ and CMJ (Gathercole et al., 2015; Petrigna et al., 2019; Sha et al., 2021)If movement different from the protocol was visually detected, the trial was repeated until 3 successful trials were recorded. Both the SJ and CMJ trials were performed with the subjects standing on using a force platform (K-Force, Kinvent Inc, Montpellier, France) at a frequency of 1000 Hz. (Fig. 1C).

Isometric Midthigh Pull (IMTP)

The IMTP testing was selected for use in this study as it is considered the gold standard in strength testing (Grgic et al., 2022; James et al., 2017). This test was performed on a portable force plate (sampling at 1000 Hz; K-Force, Kinvent Inc., Montpellier, France) using an IMTP rack. The bar height could be adjusted (3-5 cm increments) at various heights above the force plate to accommodate different-sized athletes. A rolled steel bar was positioned to correspond to the athlete's second-pull power clean position (below the crease of the hip) (Beckham et al., 2013). Athletes were strapped to the bar in accordance to previous research (Haff et al., 2005) and positioned in their self-selected mid-thigh clean position (Comfort et al., 2015) knee angle of 135–145° and a hip angle of 140–150° established in the familiarization trials, whereby the torso was upright, the feet were shoulder width apart, just behind the bar, and the knees were flexed over the toes (Dos'Santos et al., 2017). All athletes received standardized instructions to push their feet directly into the force plate" and pull as "fast and as hard as possible until being told to stop (Halperin et al., 2016). The IMTP was initiated with the countdown "3, 2, 1, pull," and subjects ensured maximal effort was applied for 5 seconds once the body was stabilized.

Cross-Fit WOD

The characteristics of the WOD used in this study, such as the weights, the number of rounds, and the repetitions performed (Table 1), were standardized throughout the study and recorded on a sheet. This document outlined the tasks the athlete had to complete in each training session. To ensure that the exercises were executed according to the specified standards, they were supervised by judges or trainers who were all certified by CrossFit® (Butcher SJ, et al,2015, Fernandez J, et al, 2015, Maté-Muñoz J.L, et al, 2017, Ponce-García T, et al, 2025).

Experimental Procedures

Determination of the Menstrual Phase

The duration of the menstrual cycle and the onset of each phase were determined using a mobile application (Mycalendar®, Period-tracker, USA, v1.746.280) (Schantz et al., 2021). A menstrual diary was used to record the date and length of menses as well as any discomfort experienced in the days preceding and during the cycle over the course of one month. The beginning of the follicular phase was indicated by the onset of menses, while the ovulatory phase was determined to fall between 70 and 75% of the individual menstrual cycle length (i.e., from the 20th to the 23rd day of the menstrual cycle for a regular cycle of 28 days (Carmichael et al., 2021). By following these procedures, the participants' cycles were aligned, allowing for testing to be implemented in the same cycle phases. The participants collected this data for one complete menstrual cycle, starting with the phase randomly allocated.

Ethical Aspects of The Research

The experimental protocol was approved by the Institutional Ethics Committee of the University of Applied and Environmental Sciences UDCA (Sports science program (CV20-24-2025), in accordance with the latest update of the Declaration of Helsinki (2013).

Data Analysis

All statistical tests were performed using JASP 0.18.3 (University of Amsterdam, Amsterdam, The Netherlands). Data are expressed as means ± 1 standard deviation (SD) in the text and tables, and as means ± 1 standard error (SE) in the figures. The normality of the variables was analyzed using the Shapiro-Wilk test. The temporal analysis of the measured variables was performed using one-way repeated-measures ANOVA and the nonparametric Friedman test. The effect size was evaluated with η^2p (partial eta-squared), where $0.01 < \eta^2p < 0.06$ indicates a small effect; $0.06 < \eta^2 < 0.14$, a medium effect; and $\eta^2 > 0.14$, a large effect (Hopkins et al., 2009). We performed post hoc tests with Tukey's correction if the analyses revealed significant differences.

RESULTS AND DISCUSSION

To determine whether there are significant differences in cardiovascular and neuromuscular variables (Tables 2 and 2.1) among athletes during the follicular, ovulatory, and luteal phases, a temporal analysis of the measured variables was conducted. This analysis employed a one-way repeated-measures ANOVA with the nonparametric Friedman test. The level of significance was set at $p \leq 0.05$.

Table. 1 Crossfit® Protocol

Weeks	warm up - brake	Application	Crossfit Workout (20 min)	Repetition (Mean)	Total time (min)
1—4	Warm up: 15 min Break time:10 min	15 min	Half Cindy 5 Assisted Pull up Machine 10 Knee Push up 15 Squat	5 10 14.11	60 min
5—8	Warm up: 15 min Break time:10 min	-	Half Cindy 5 Assisted Pull up Machine 10 Knee Push up 15 Squat	5 9.58 13	45 min
9—12	Warm up: 10 min Break time:10 min	-	Cindy 5 Assisted Pull up Machine 10 Knee Push up 15 Squat	5 9.91 13.53	40 min
13—16	Warm up: 10 min Break time:10 min	-	Cindy 5 Assisted Pull up Machine 10 Knee Push up 15 Squat	5 10 14.81	40 min

Table 2. Cardiovascular and Neuromuscular I Performance Variables

variables	FP		OP		LP	F	*P*	Post Hoc	η^2p
	Mean ± SD		Mean ± SD		Mean ± SD				
HRV [RMSSD]	55.74 ± 31.50		45.21 ± 15.43		45.69 ± 13.19	0.830	0.443		0.038

variables	FP		OP		LP	F	*P*	Post Hoc	η^2p
HGS L [Kg]	27.4 ± 4.37		26.7 ± 3.38		29.5 ± 0.70	0.280	0.757		0.013
HGS R [Kg]	29.3 ± 3.55		29.7 ± 4.99		35.6 ± 7.23	0.182	0.834		0.009
PUT L [Kg]	23.2 ± 3.05		23.5 ± 3.14		23.5 ± 2.97	0.032	0.969		0.002
PUT R [Kg]	24.3 ± 3.64		24.7 ± 3.62		24.5 ± 3.58	0.051	0.951		0.002
MST [Kg]	47.6 ± 6.53		48.3 ± 6.59		48.0 ± 6.39	0.041	0.959		0.002
REP	11.6 ± 2.35		11.8 ± 2.21		11.6 ± 1.87	0.033	0.967		0.002
CMJ MSL [Kg]	61.8 ± 6.10		61.1 ± 5.61		62.0 ± 6.08	0.114	0.893		0.005
CMJ MSR [Kg]	65.1 ± 7.93		77.5 ± 32.4		65.2 ± 7.91	13.260	0.050		0.038
CMJ TOTAL [Kg]	127.0 ± 12.09		93.4 ± 33.8		127.3 ± 12.0	11.921	0.050		0.362
FT [sc]	0.46 ± 0.04		0.46 ± 0.03		0.46 ± 0.01	0.233	0.793		0.011
JH [cm]	26.3 ± 4.45		26.7 ± 3.69		26.6 ± 4.08	0.041	0.960		0.002
RFD [N/s]	2682.1 ± 748.4		2322.6 ± 664.0		2682.2 ± 748.4	1.242	0.299		0.056
MP [W]	2210.2 ± 398.2		2320.4 ± 549.4		2210.3 ± 398.2	0.294	0.747		0.014

FP: follicular phase, OP: ovulation phase: LP: luteal phase, H: H-value, *p*: p-value, (η^2p): Partial Eta squared effect size, HRV [RMSSD]: Hear rate variability [root mean square of successive differences], HGS L [Kg]: Handgrip strength left, HGS R [Kg]: Handgrip strength right, PUT L [Kg]: Push up test left, PUT R [Kg]: Push up test right, MST [Kg]: max strength total, REP: repetitions, CMJ MSL [Kg]: Countermovement jump max strength left, CMJ MSR [Kg]: Countermovement jump Max strength right, CMJ TOTAL [Kg]: Countermovement jump max strength Total, FT [sc]: flight time, JH [cm]: jump height, RFD [N/s]: peak rate of force development, MP [W]: Max power.

Table 2.1. Neuromuscular Ii Performance Variables

Variables	FP		OP		LP	F	*p*	Post Hoc	η^2p
SJ MSL [Kg]	56.3 ± 7.01		57.4 ± 9.01		57.6 ± 8.98	0.103	0.902		0.005
SJ MSR [Kg]	59.9 ± 5.78		62.2 ± 6.03		62.3 ± 6.05	0.782	0.464		0.036
SJ TOTAL [Kg]	116.2 ± 10.5		119.6 ± 12.6		119.9 ± 12.5	0.439	0.648		0.020
FT [sc]	0.42 ± 0.04		0.43 ± 0.04		0.44 ± 0.04	0.586	0.561		0.027
JH [cm]	22.4 ± 4.95		23.0 ± 4.54		23.4 ± 4.35	0.178	0.838		0.008
RFD [N/s]	1500.4 ± 354.3		1728.2 ± 407.6		1728.6 ± 407.5	1.703	0.194		0.075
IMTP L [Kg]	85.5 ± 16.0		84.0 ± 13.7		84.2 ± 13.6	0.051	0.950		0.002
IMTP R [Kg]	82.0 ± 14.0		82.1 ± 14.0		82.3 ± 14.2	9.814×10^{-4}	0.999		4.673×10^{-5}

Variables	FP		OP		LP	F	*p*	Post Hoc	η^2p
IMTP TOTAL [Kg]	167.6 ± 23.7		166.1 ± 21.4		166.5 ± 21.3	0.019	0.981		9.132 x 10^{-4}

Discussion

This study aimed to analyze the effects of the MC on the internal and external load of women CrossFit® athletes in a real training situation. This was done by comparing cardiovascular and neuromuscular test results between three menstrual cycle phases, the latter serving as controls over 4 weeks. When analyzing female athletes, we found no statistically significant differences for the MC overall. These findings suggest that the MC process does not alter performance at an amateur level (Schlegel & Křehký, 2022). The choice of statistical test may not have influenced the non-significant results, as there were only minor impacts on physical performance in athletes, as well as on perceived performance and training load. Furthermore, the absence of a relationship between performance outcomes and menstrual cycle phase observed in the present study aligns with previous research reporting stable neuromuscular and cardiovascular performance across the menstrual cycle (Blagrove et al., 2020; Colenso-Semple et al., 2023). These findings may be explained by the predominance of tonic or well learned motor patterns and the relatively high inter-individual variability in hormonal responses, which can attenuate phase-specific effects at the group level.

In contrast, studies conducted in other sporting contexts have reported menstrual cycle-related fluctuations in performance (Wen et al., 2025), particularly in endurance-based or skill-dependent sports, where prolonged physiological stress, pacing strategies, or fine motor control may be more sensitive to hormonal variations. Differences in task intensity, duration, metabolic demands, and neuromuscular complexity (Legerlotz & Nobis, 2022) may therefore account for the apparent discrepancies between sports. With high-intensity training contexts such as CrossFit®, performance relies heavily on short-duration, explosive actions and grip-intensive tasks, which may be less susceptible to transient hormonal fluctuations. This is supported by the lack of variation observed in reactive jump performance and explosive strength tasks across menstrual cycle phases (Romero Moraleda et al., 2019; Julian et al., 2017) as well as the relevance of handgrip strength to repeated high force gripping demands, characteristics of CrossFit® workouts of the day (WODs)

Throughout the study, we observed that the performance outcomes of the heart rate variability test remained stable. This is crucial for athletes because, typically, HRV does not fluctuate significantly based on the different phases of the menstrual cycle. It first responds with a stable trend, indicating readiness due to cardiac parasympathetic activity (Barreto et al., 2022; Claiborne et al., 2021). On the other hand, handgrip strength was not found to be associated with menstrual cycle phases (Dam et al., 2022; Kishali et al., 2006; Sarwar et al., 1996; Vogel et al., 2023). However, it could be linked to improved performance in the workout of the day, depending on the load percentage (Huebner et al., 2023). Therefore, it is relevant to examine whether the variables assessed in the present study followed a similar pattern across the menstrual cycle. Specifically, this approach allows evaluation of whether greater hormonal variation is associated with meaningful changes in performance outcomes in women athletes. Our findings align with previous research reporting no significant differences in strength or power performance (IMTP) across menstrual cycle phases (Blagrove et al., 2020; Colenso-Semple et al., 2023; García-Pinillos et al., 2022; Meignié et al., 2021; Romero-Moraleda et al., 2019; Sipavičienė et al., 2013).

In contrast, handgrip strength (HGS), although also unaffected by menstrual cycle phase in the present study, represents a performance metric more closely related to task-specific neuromuscular demands. In the context of CrossFit® many workouts of the day (WODs) involved repeat high force gripping actions (e.g. Barbell cycling, pull-ups, kettlebell swings, gymnastics–based movements), making HGS a relevant indicator of performance capacity despite its lack of association with menstrual cycle phase (Dam et al., 2022; Kishali et al., 2006; Sarwar et al., 1996; Vogel et al., 2023). Accordingly, while menstrual cycle phase did not influence HGS, grip strength may still meaningfully contribute to WOD performance, depending on external load, volume, and movement selection (Huebner et al., 2023). Collectively, these results suggest that, at least at the group level and within high-intensity training contexts, hormonal fluctuations across the menstrual cycle do not appear to systematically influence neuromuscular performance outcomes.

Research Contribution

This study examines important cardiovascular and neuromuscular performance factors that could be affected by the menstrual cycle in female athletes participating in CrossFit®. These factors include heart rate variability, hand grip strength, push-ups, isometric mid-thigh pull, and counter movement jump, which were evaluated using force plates validated by scientific research. The findings indicate that CrossFit® athletes do not exhibit significant differences in cardiovascular variables and neuromuscular aspects across sports. This research provides a valuable guide for identifying aspects of performance and sport profiles in female CrossFit® athletes. It enables coaches to make informed decisions about strength and endurance periodization programs using objective and reliable measures. Moving forward, it paves the way for research involving a broader range of athletes' populations and various physiological variables.

Limitations

Our study has several limitations, including: first, although G*Power was used to estimate the required sample size given the exploratory nature of the study, future research with a larger sample is needed to confirm the present findings. Second, the relatively small sample of female CrossFit® athletes limits the generalizability of the results to other populations. Third, the short duration of the study may have restricted the ability to detect potential changes across menstrual cycle phases. Extending the observation period would allow for a more detailed examination of phase -specific physiological responses. Despite these limitations, the present study provides a methodological foundation for future large-scale and longitudinal investigations aimed at improving the understanding of physiological responses and performance outcomes in female athletes.

Suggestion

While the present findings provide preliminary evidence on the physiological aspects of CrossFit® performance in female athletes, they are specific to this population. They may not be generalizable across age groups or competitive levels. Future studies should include larger and more diverse samples, as well as longer study durations, to enhance the external validity of the results. Further research is recommended to examine differences across competition levels, including analyses of velocity-Based Training and physiological biomarkers. Additionally, incorporating direct hormonal assessments may contribute to a more comprehensive understanding of the relationship between hormonal fluctuations during the menstrual cycle and performance. Finally, future investigations should explore the influence of biomechanical variables on sport-specific kinematic and performance outcomes in CrossFit® athletes.

CONCLUSION

The findings of the present study indicate that the menstrual cycle does not exert a significant influence on internal and external training load, nor on cardiovascular and neuromuscular responses, in amateur female CrossFit® athletes during real training sessions. Across the assessed menstrual cycle phases, performance and physiological markers remained stable, suggesting that phase specific hormonal fluctuations do not systematically affect short term training responses within this population. From an applied perspective, these results suggest that systematic adjustment of strength and endurance training programs based solely on menstrual cycle phase may not be necessary for CrossFit® athletes. Instead, the training prescription may benefit more from an individualized, performance- and readiness-based approach that accounts for external load, fatigue, and task-specific demands. Menstrual cycle considerations may still be relevant in specific contexts such as elite populations, prolonged training periods, or symptom-driven variability. Still, these factors were beyond the scope of the present investigation.

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AUTHOR CONTRIBUTION STATEMENT

CY, DC, JDP was responsible for the design and conceptualization of the current research and the drafting of the manuscript. OH, GJ, LV, JA and NO was responsible for analyzing the data and discussing the findings. The researchers co-authored the manuscript

AI DISCLOSURE STATEMENT

The author used [Open evience] during the preparation of this work for compilation of scientific articles. After using the tool/service, the author thoroughly reviewed and edited the content as needed and takes full responsibility for the content of the publication. The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

CONFLICTS OF INTEREST

This study did not receive any external funding and the authors declare no conflicts of interest. No funding was received for this research.

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